Use of EMVAP to Evaluate 1-hour NAAQS Compliance with Long-term Emission Rates

Bob Paine, AECOM and Dr. Eladio Knipping, EPRI

Presentation to EPA RSL Workshop

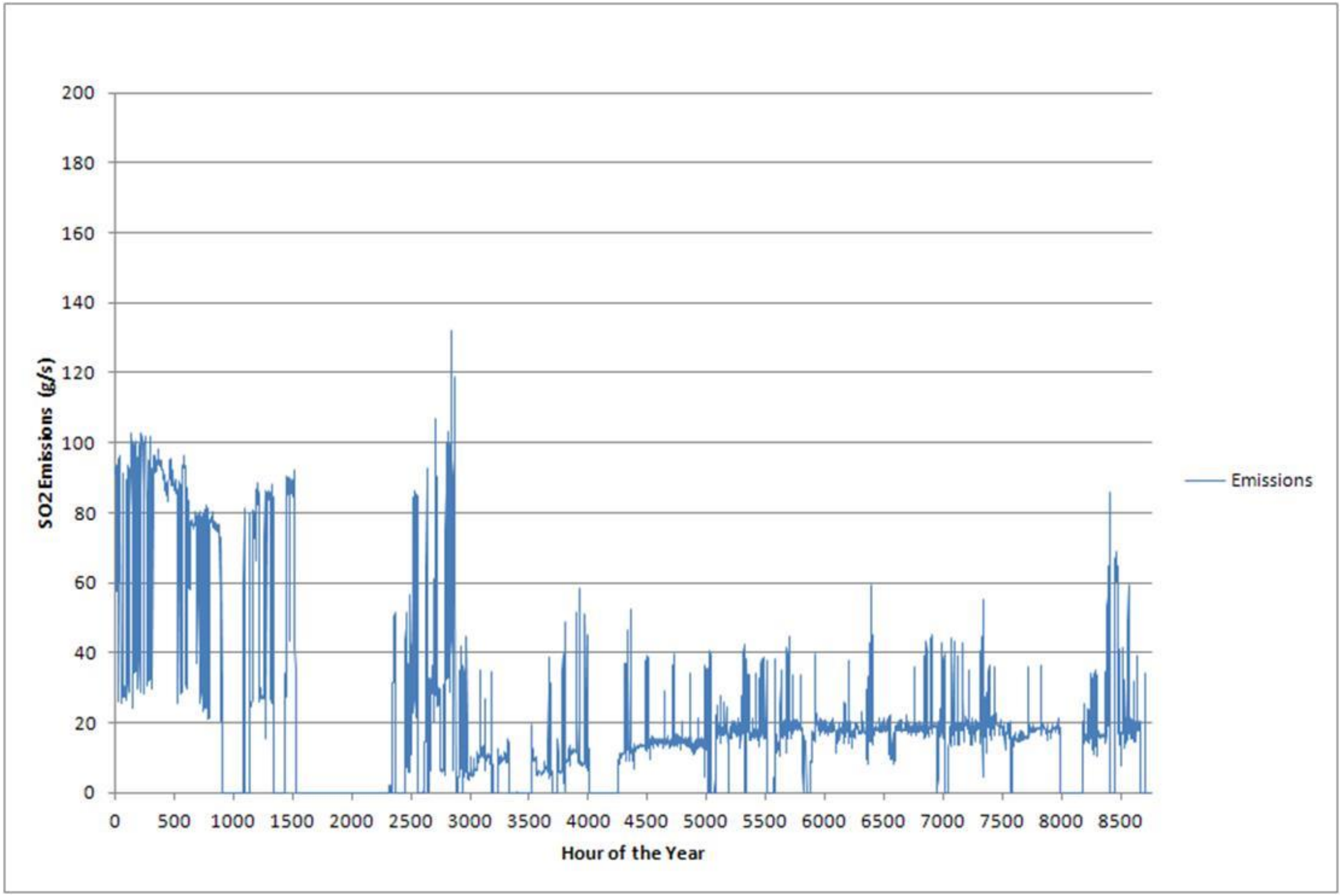
May 20, 2014

Outline of Presentation

- **Emission Variability Processor (EMVAP) Design and Evaluation**
- **Applicable EPA SO_2 Nonattainment Guidance Issue for Emissions Averaging Time**
- **EMVAP Example that Addresses the EPA Guidance**

Design of EMVAP and Evaluations Against Field Data

Consider a Time Series of Hourly Emissions



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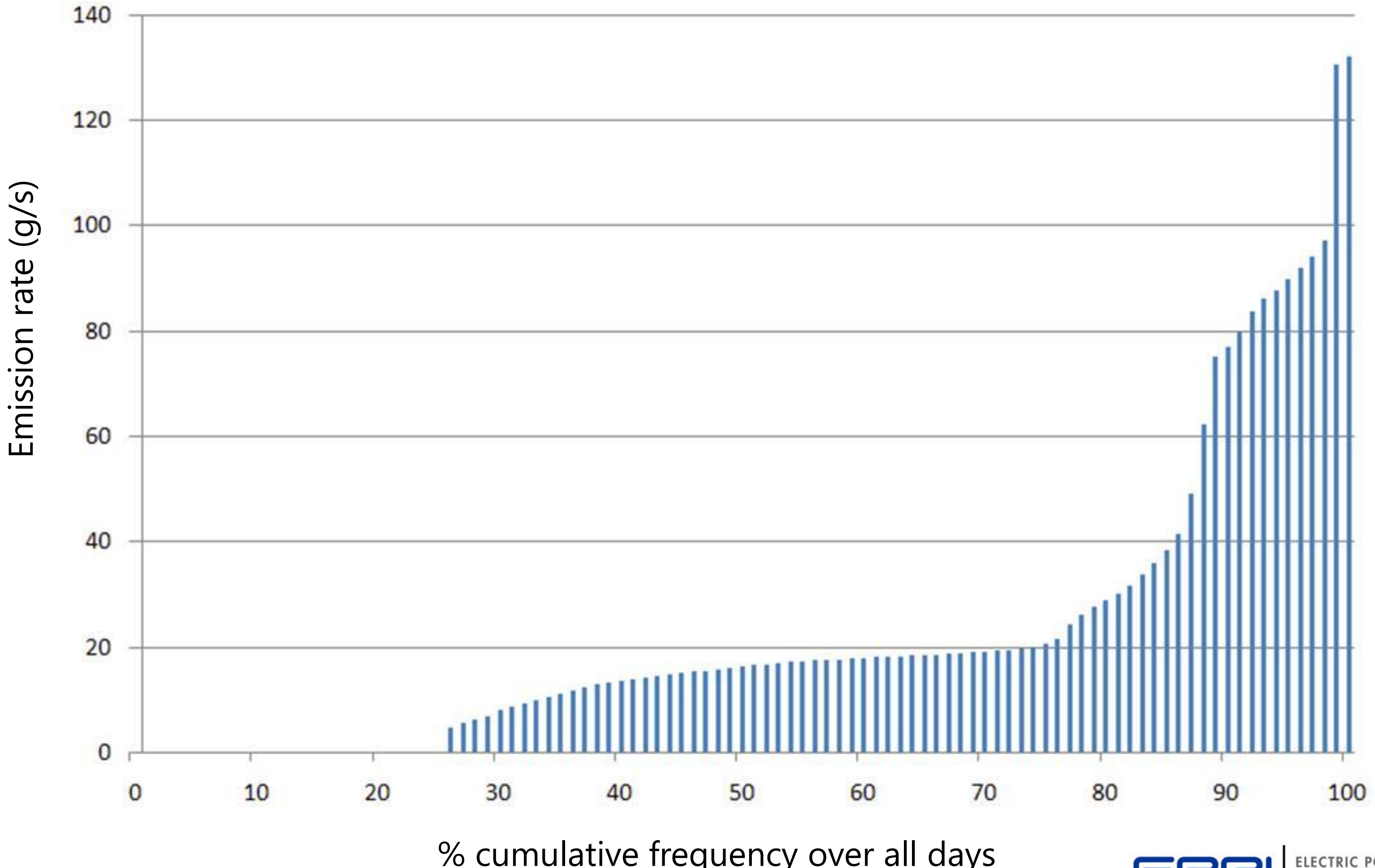
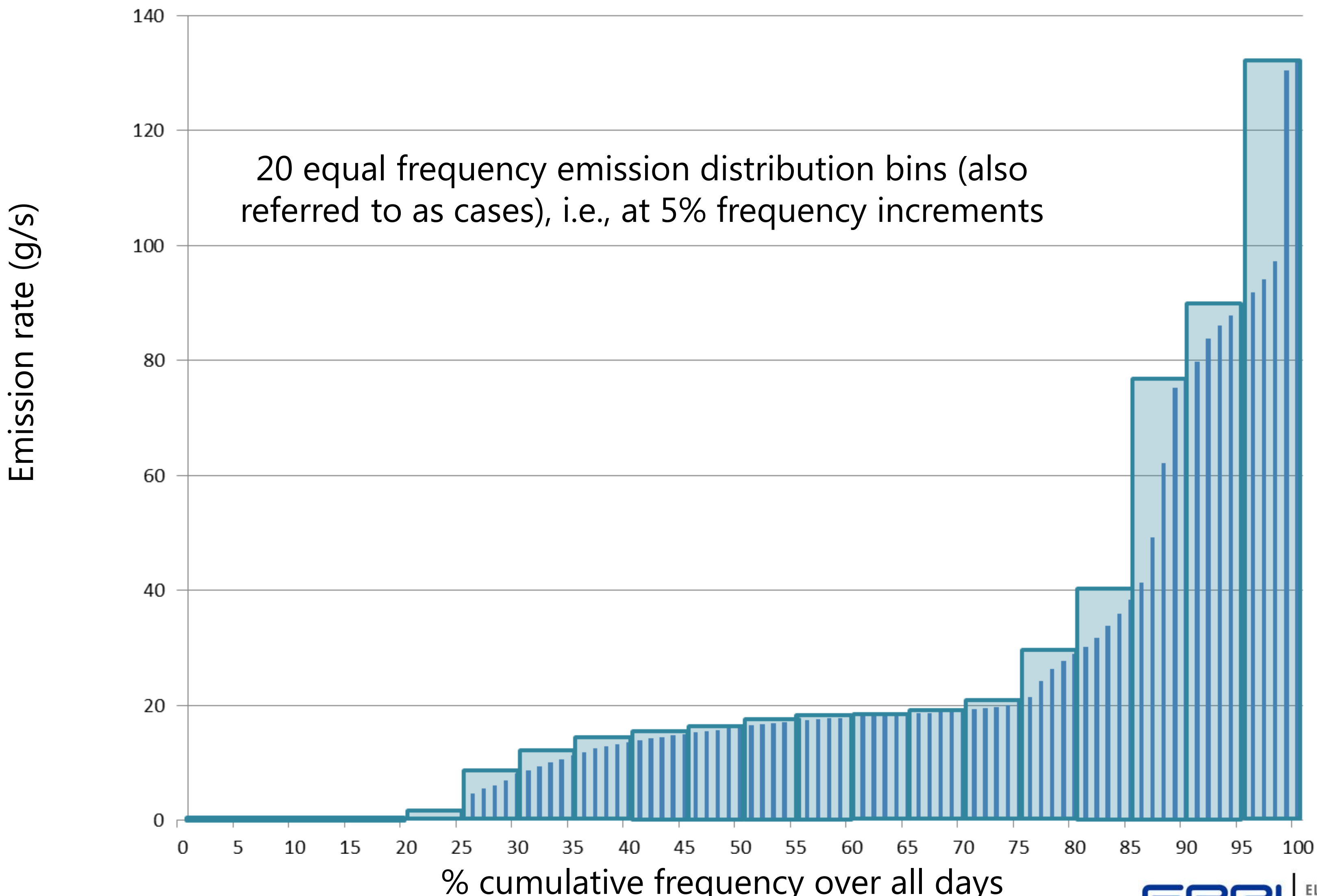
Cumulative Frequency Distribution of the Same Hourly Emissions



For EMVAP, Place the Emissions Distribution into Discrete "Bins"



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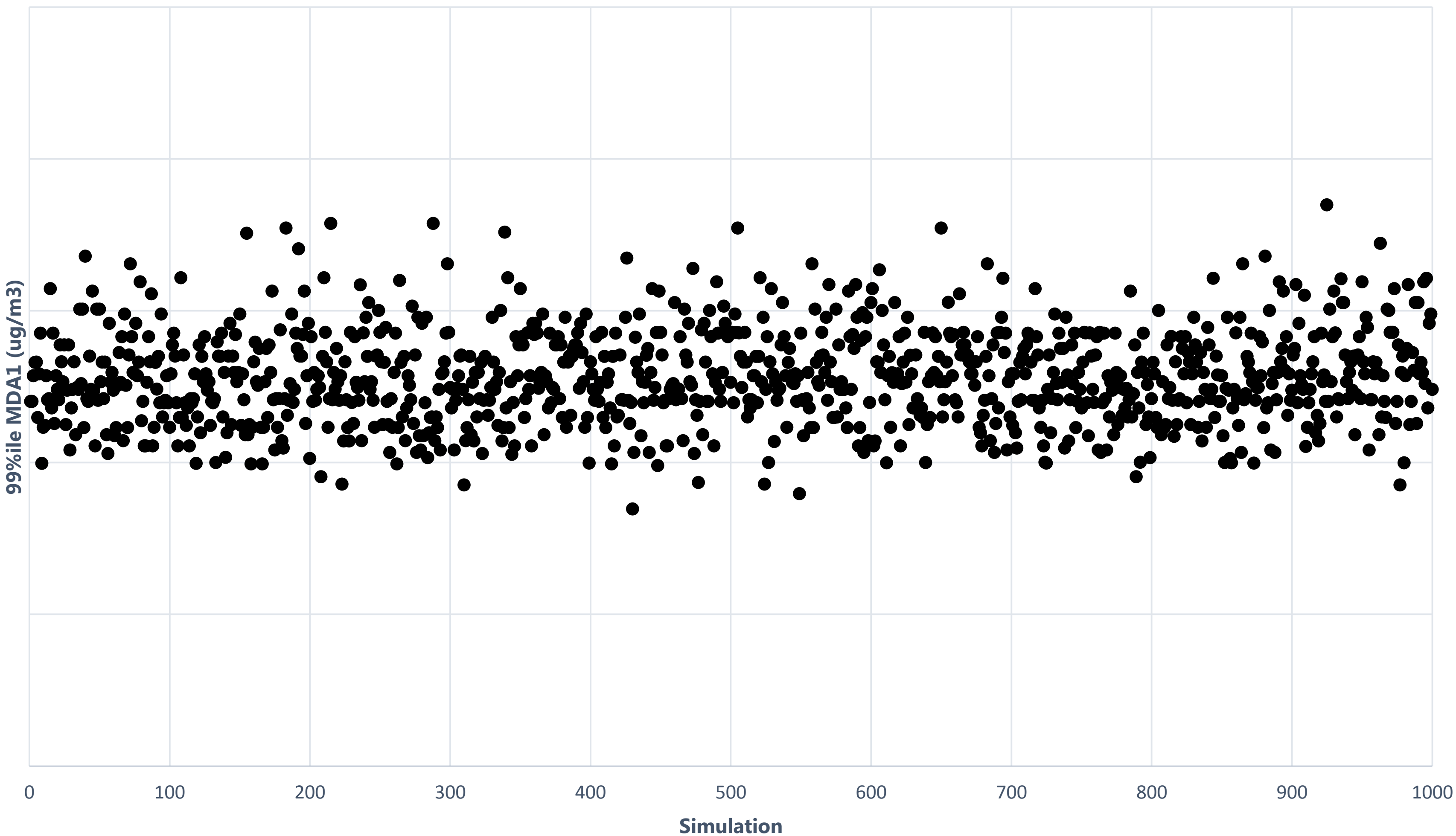
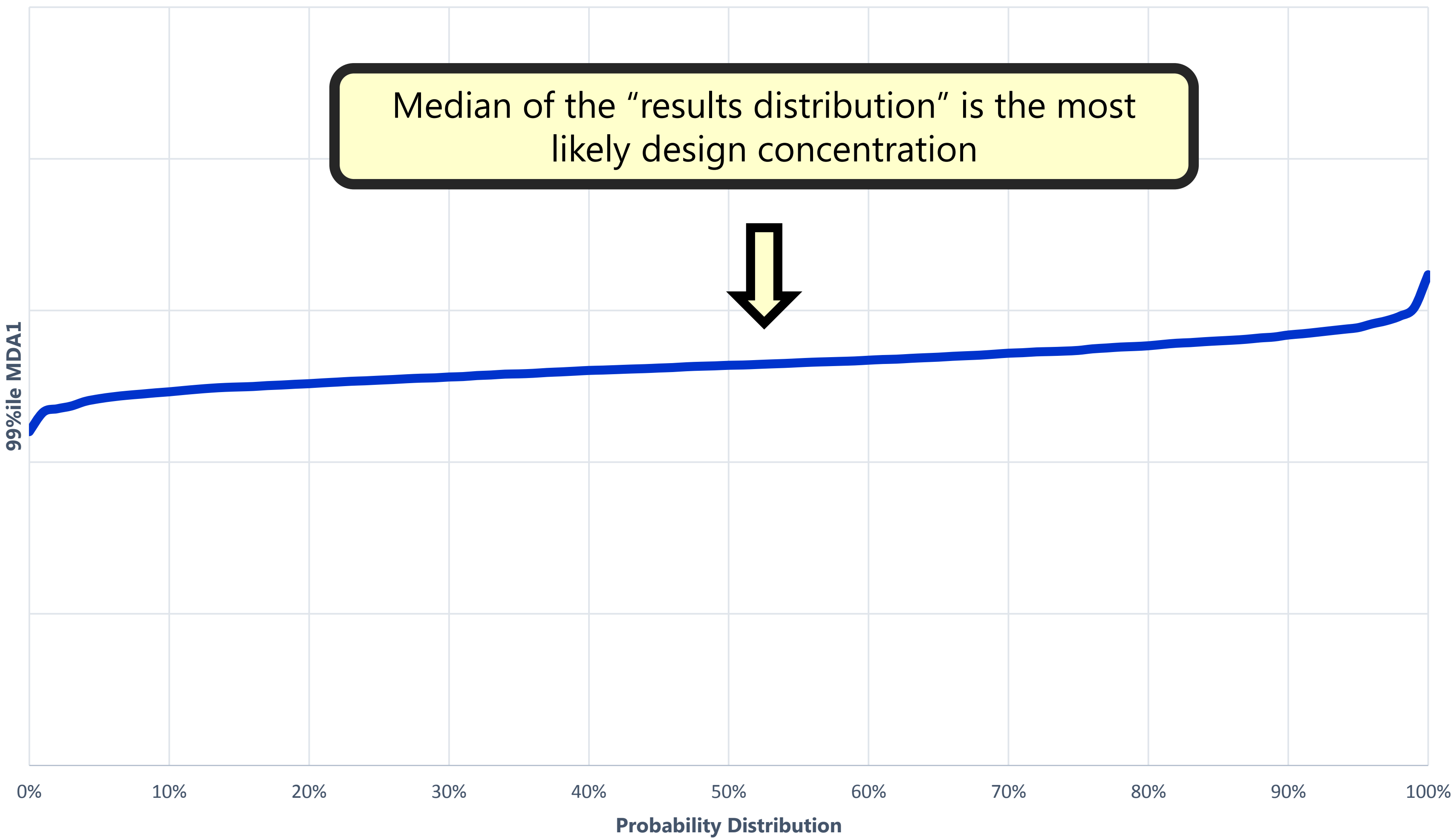
EMVAP Design Concentration Results over 1000 Simulated Years



EMVAP Results Are Expressed as a Distribution



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EMVAP Testing with SO_2 Evaluation Databases

- **Lovett Generating Station:**
  - 1988, complex terrain within Hudson River Valley in New York
  - 1 full year test case, 8 monitors
- Clifty Creek Generating Station:
  - 1975, Ohio River Gorge in Indiana
  - 1 full year with 3 units with differing load profiles, 6 monitors
- Kincaid Power Station
  - 1980, flat corn fields of Illinois
  - Partial year case, 1 stack, 28 monitors

Overall Evaluation Results for EMVAP

- Evaluation results suggest that EMVAP can provide a realistic design concentration estimates, even when a source has infrequent high emissions or a wide variety of emissions

- EMVAP's assumption that hourly emissions are random and independent rather than clustered adds conservatism to the design concentrations

- Use of EMVAP results in design concentrations (using median of the design concentration distribution) that are at least as high as modeling with actual hourly emission rates

- This is true for the 50^{th} percentile results, and EMVAP is even more protective for higher percentile results

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Is EMVAP Protective of Air Quality for Your Case?

- Some commenters have wondered about certain cases in which there are unique emission distributions such as seasonal emission differences
- Is EMVAP protective of air quality in those situations?
- Fortunately, this can be easily tested, as follows:

  1) Construct an hourly emissions file (at least 1 year in duration) for the case to be tested

  2) Run AERMOD with the actual hourly emissions and obtain a design concentration

  3) Run the EMDIST pre-processor with this emissions distribution to obtain emission "bins" for testing with EMVAP

  4) Run EMVAP with these emission bins and compare the design concentration: pick the 50th or some higher percentile that shows results at least as high as the AERMOD result for the actual hourly emissions

  5) If this works, then EMVAP with the selected percentile of results can be used

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SO_2 Nonattainment Modeling Guidance: Critical Value

- Previous EPA guidance:
  - SIP emissions limits should apply to the averaging time of the applicable NAAQS
  - This becomes complicated when the NAAQS is a 1-hour average, but it is in a probabilistic form, so that infrequent higher emissions would not threaten compliance with the NAAQS
- **"Critical value"** =
  - hourly emission rate that would result in the 99^{th} percentile of daily maximum hourly SO_2 concentrations at the 1-hour NAAQS, given representative meteorological data for the area.

EPA Consideration

- After considering [various] comments, and analyzing the impact of emissions variability on air quality …

- EPA expects that it may be possible in specific cases for states to develop control strategies that account for

  - **variability in 1-hour emissions rates through emission limits with averaging times that are longer than one hour,**

  - but still provide for attainment of the 2010 SO_2 (or NO_2) NAAQS

Long-Term Average vs. Critical Value

- EPA would expect that any emission limit with an averaging time longer than 1 hour would need to reflect a downward adjustment to compensate for the loss of stringency inherent in applying a longer term average limit.

  – **Long-term average emissions rate < "critical value"**

- The downward adjustment depends upon the intermittency and variability of the longer-term emissions (more variability → more downward adjustment)

- **The Emissions Variability Processor (EMVAP) developed by EPRI can be used as a tool to address emissions averaging**

Determining Long-Term Compliance Emission Rate Using EMVAP with Critical Value Analysis*

Step 1

Find Critical Value (AERMOD) with constant 1-hour emission rate

Step 2

Choose Emission Distribution and Emission Cases for EMVAP

Step 3

Run AERMOD with EMVAP Emission Cases

Create Binary Files for all of the Emission Distribution Cases

Step 4

EMVAP

Part 1:

1st EMVAP run provides scaling estimate for final long-term emission rate.

Part 2:

Re-Run EMVAP with refined background and scaled emissions to verify NAAQS compliance with the final long-term emission rate.

The Critical Value is the constant 1-hour emission rate that results in NAAQS compliance.

The CV acts as a threshold emission rate, that the long-term average emission rate **cannot exceed**.

*** This method will be illustrated for a single emission source for simplicity.**

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Example Application of EMVAP: Step 1

- **Determine the Critical Value in the Traditional Manner Using AERMOD**

- For a single source, run using:
  - representative peak normal operating stack parameters
  - input emission rate
  - background concentration

  - scale the emission rate as needed to show marginal NAAQS compliance is the "critical value"

- In this example case (modeled in flat terrain), we have
  - *Stack Height: 122 m*
  - *Stack Diameter: 5.2 m*
  - *Stack Temp: 416 K*
  - *Exit Velocity: 23 m/s*
  - *Ambient SO_2 background: 15 ppb (39.3 μg/m^3)*

  – *Critical Value emission rate is determined to be 327 g/s*

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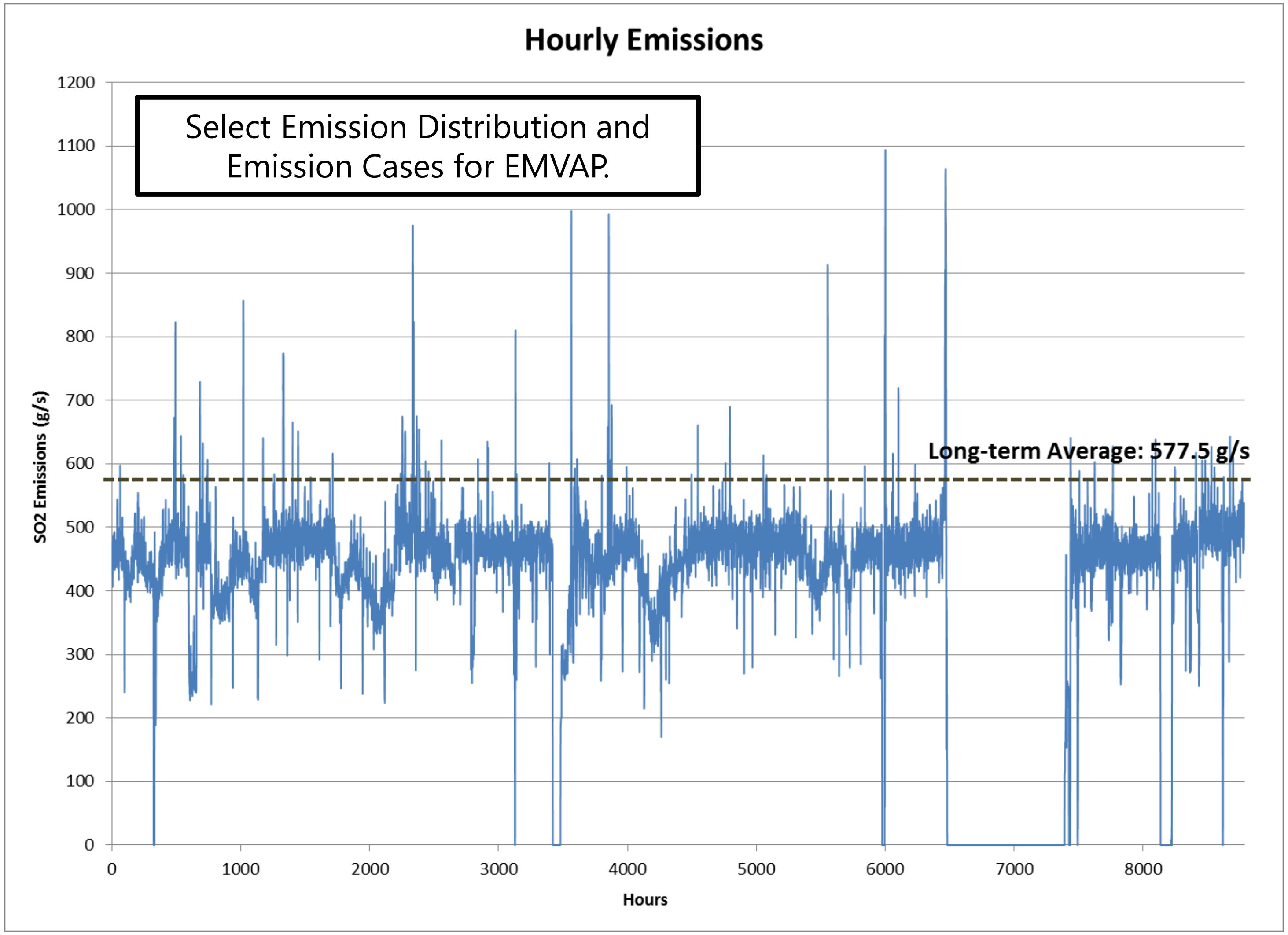
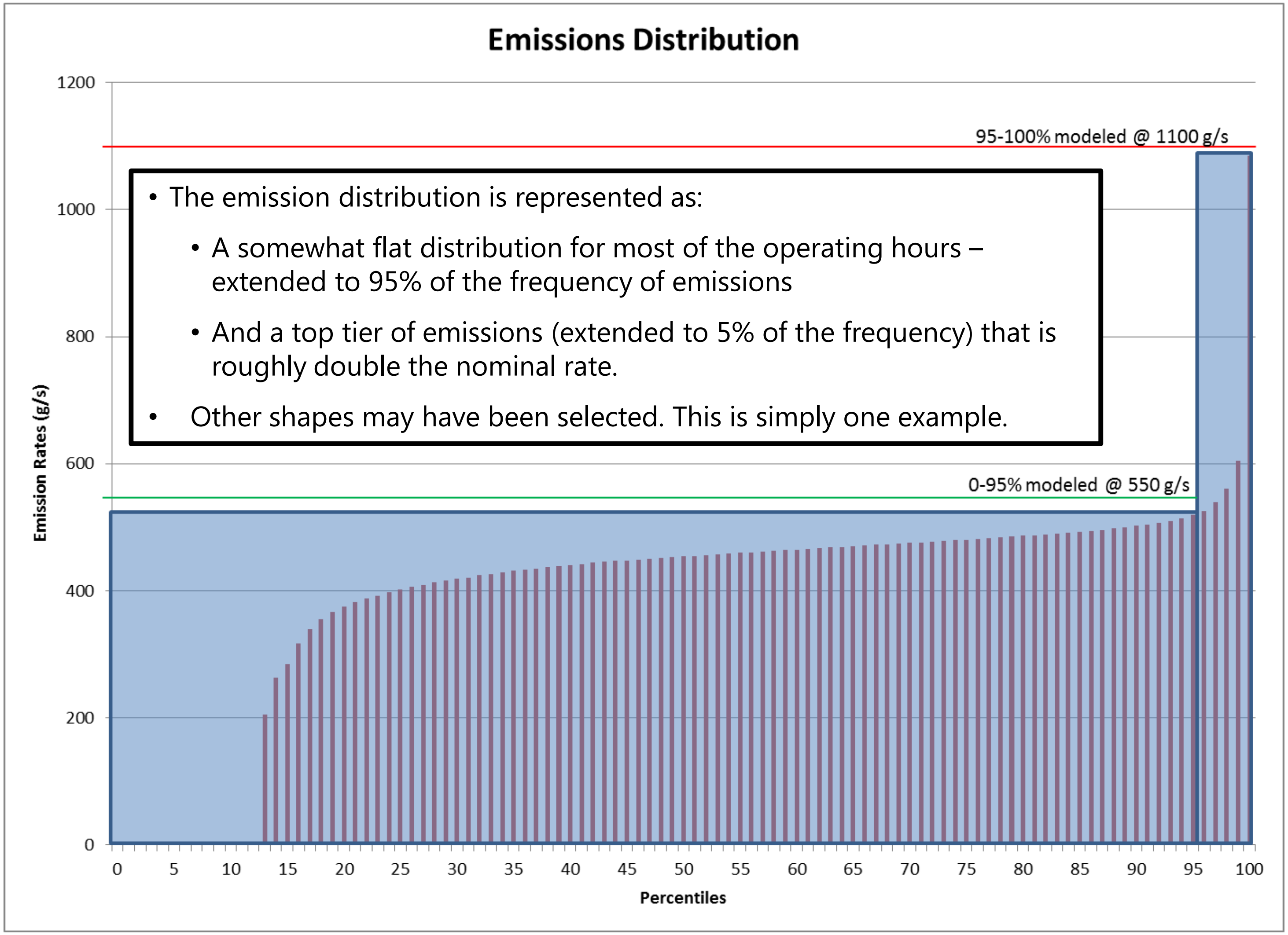
Example Application of EMVAP: Step 2



Step 2 (Continued): Emissions Distribution



- The emission distribution is represented as:
  - A somewhat flat distribution for most of the operating hours – extended to 95% of the frequency of emissions
  - And a top tier of emissions (extended to 5% of the frequency) that is roughly double the nominal rate.
- Other shapes may have been selected. This is simply one example.

Example Application of EMVAP: Step 3

Generate AERMOD Binary Files for each Emission Distribution case.

AERMOD

If the stack parameters vary between the emission distribution bins, a separate source must be modeled for each emission bin*.

Each source must be run with:

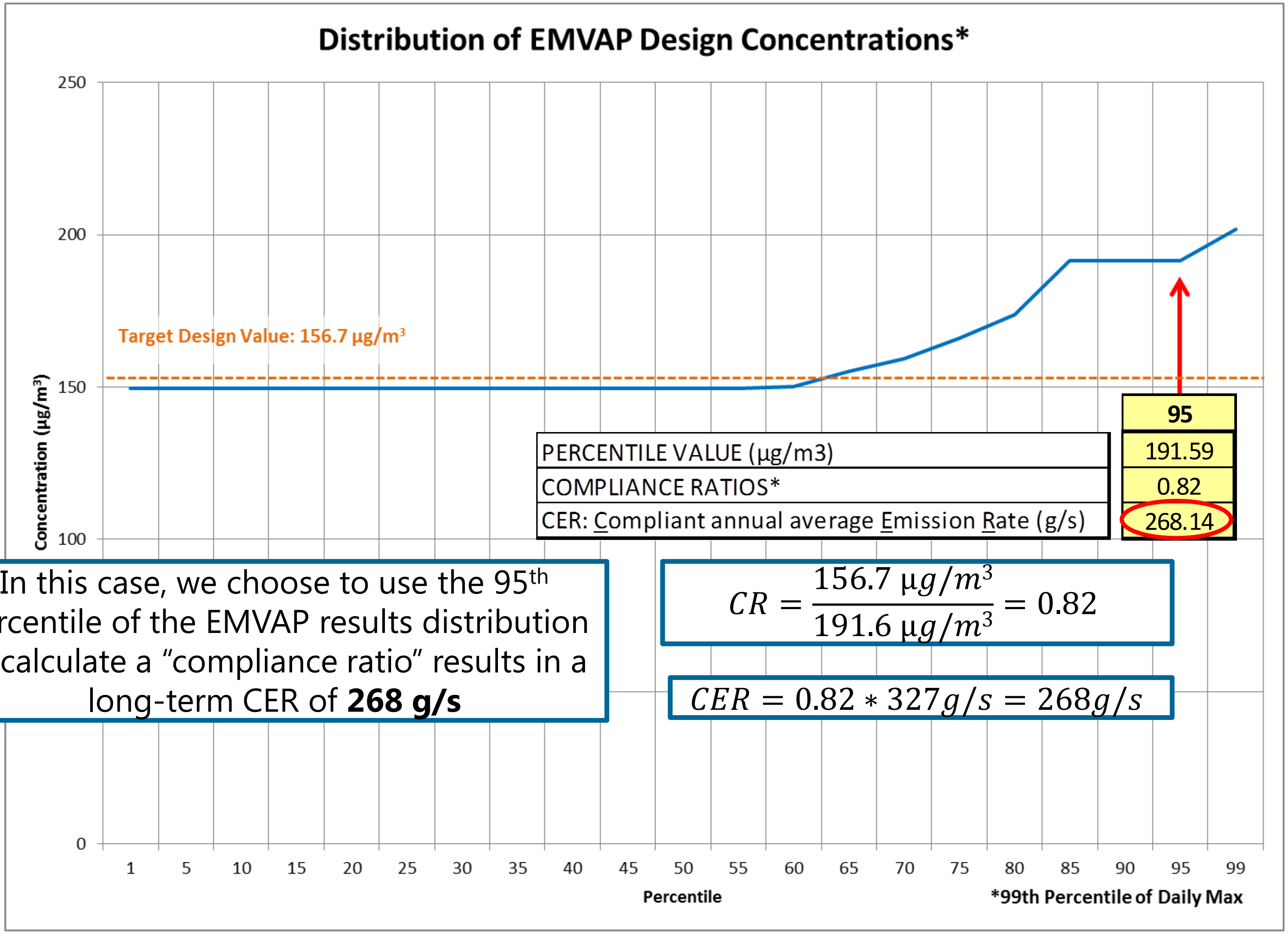
- 1 g/s emission rate
- corresponding stack parameters for that bin in the emissions distribution

These binary files will be used in the EMVAP run.

*Refer to EMVAP User's Guide for details.

Example Application of EMVAP: Step 4a

*Based on a Target Design Value of 156.7 µg/m3 (which takes into account an ambient background of 39.3 µg/m3)



	95
PERCENTILE VALUE (µg/m3)	191.59
COMPLIANCE RATIOS*	0.82
CER: Compliant annual average Emission Rate (g/s)	268.14

In this case, we choose to use the 95th percentile of the EMVAP results distribution to calculate a "compliance ratio" results in a long-term CER of **268 g/s**

$$CR = \frac{156.7\ \mu g/m^3}{191.6\ \mu g/m^3} = 0.82$$

$$CER = 0.82 * 327 g/s = 268 g/s$$

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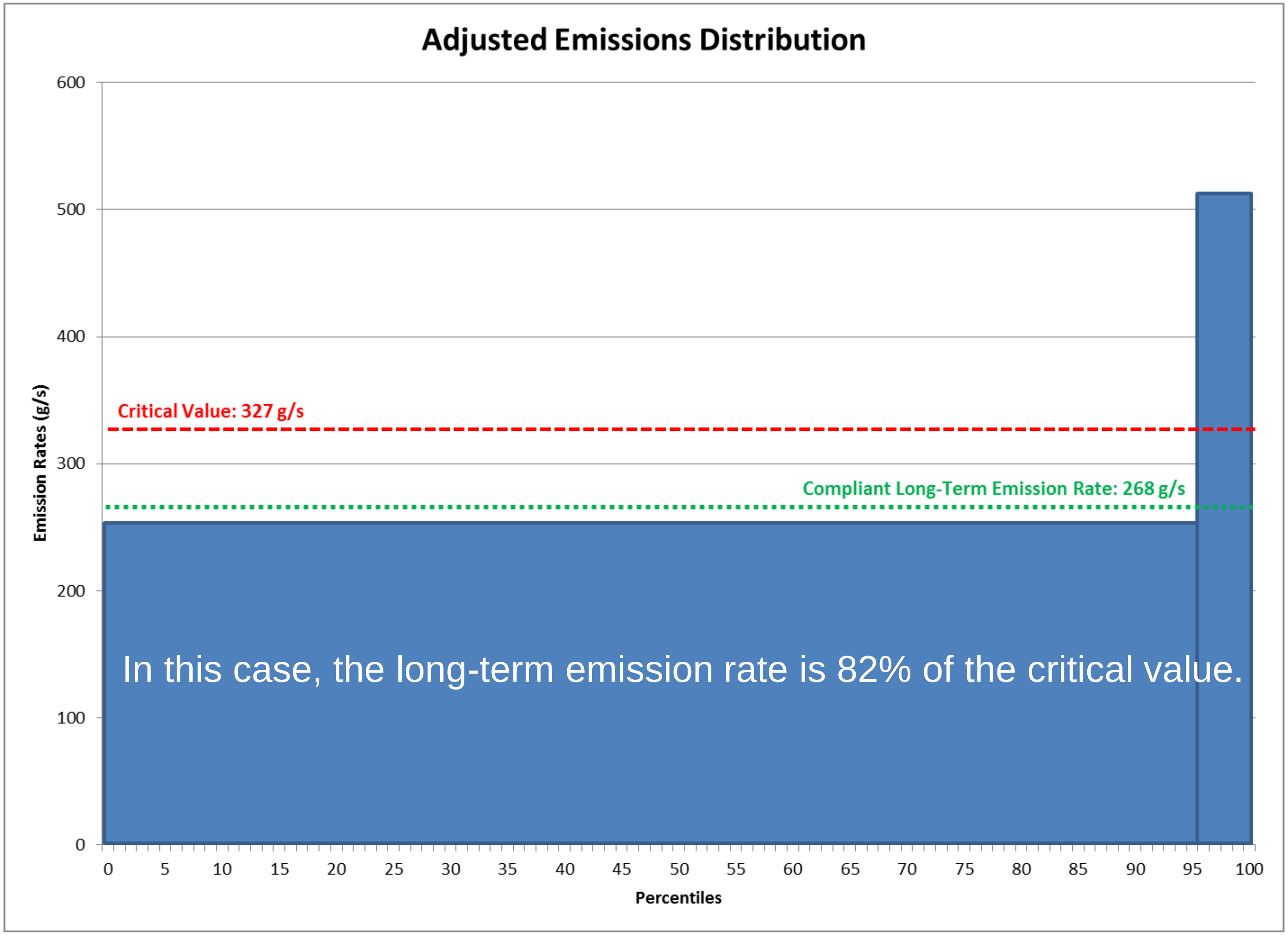
Example Application of EMVAP: Step 4b

Rerun EMVAP with scaled emission rates to verify modeled NAAQS compliance.



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Overall Conclusions

- EMVAP is a useful tool for applications involving new or modified sources
- The EMVAP approach is consistent with the probabilistic form of the 1-hour SO_2 and NO_2 NAAQS
- Evaluations of EMVAP consistently show modest levels of conservatism, even using the median of the "results distribution"
- EMVAP can be used to evaluate long-term average emission limits that are protective of a 1-hour NAAQS standard – we show an example of how this can be done

- Public domain tool:
  - http://sourceforge.net/projects/epri-dispersion/
  - Old version currently on site… new version will be posted within first half of 2014

More Complete EMVAP Presentation Starts Here

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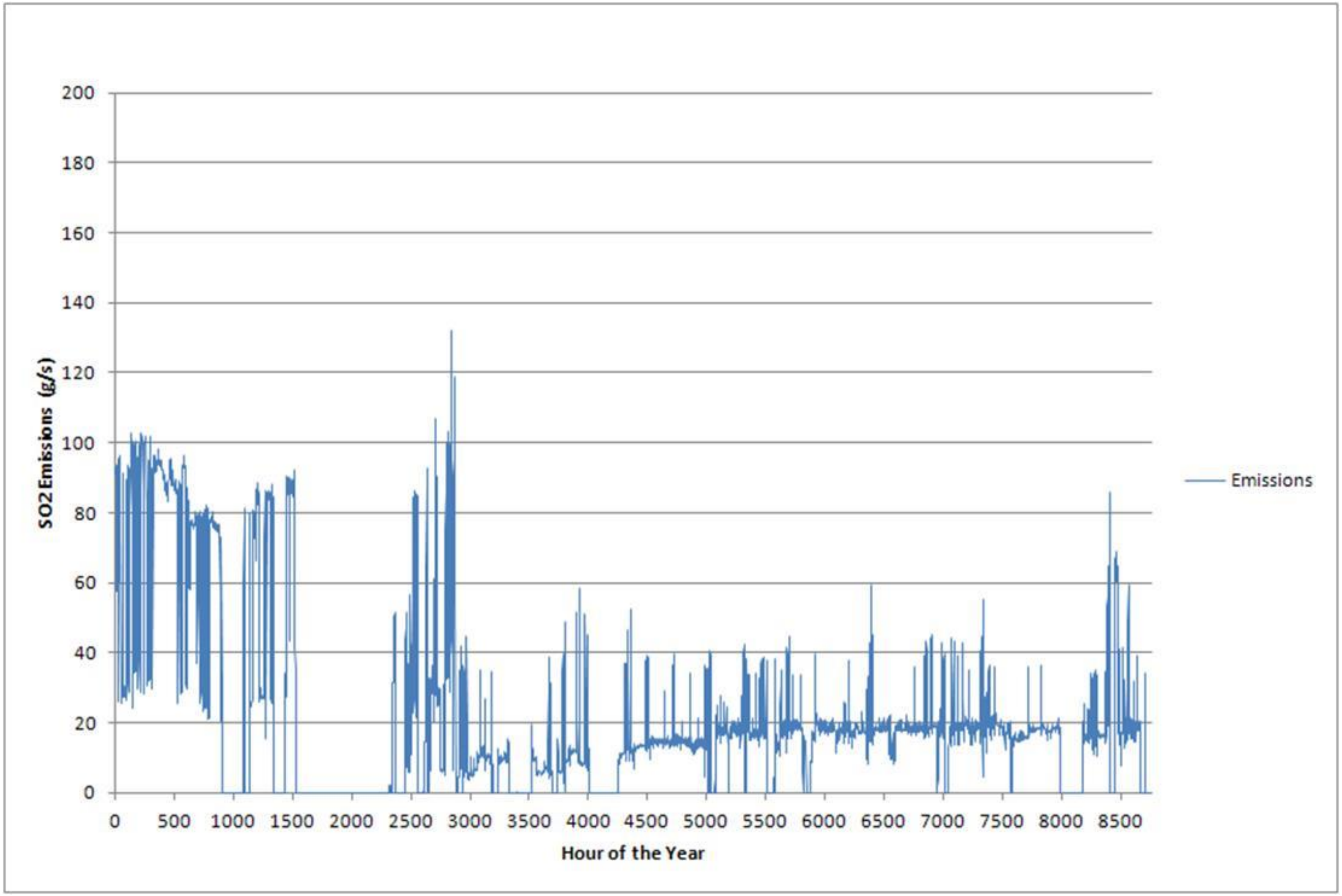

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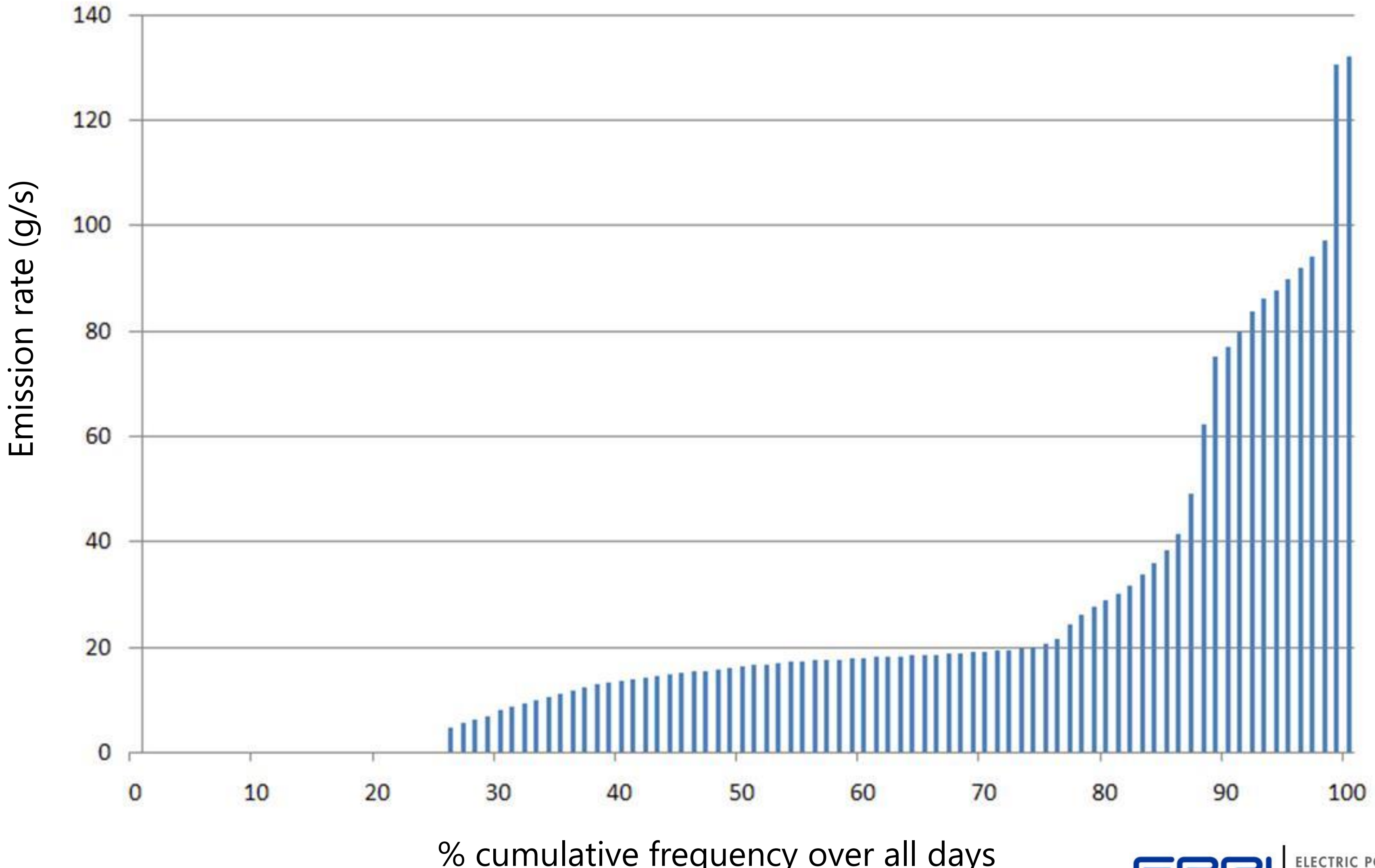
Cumulative Frequency Distribution of the Same Hourly Emissions



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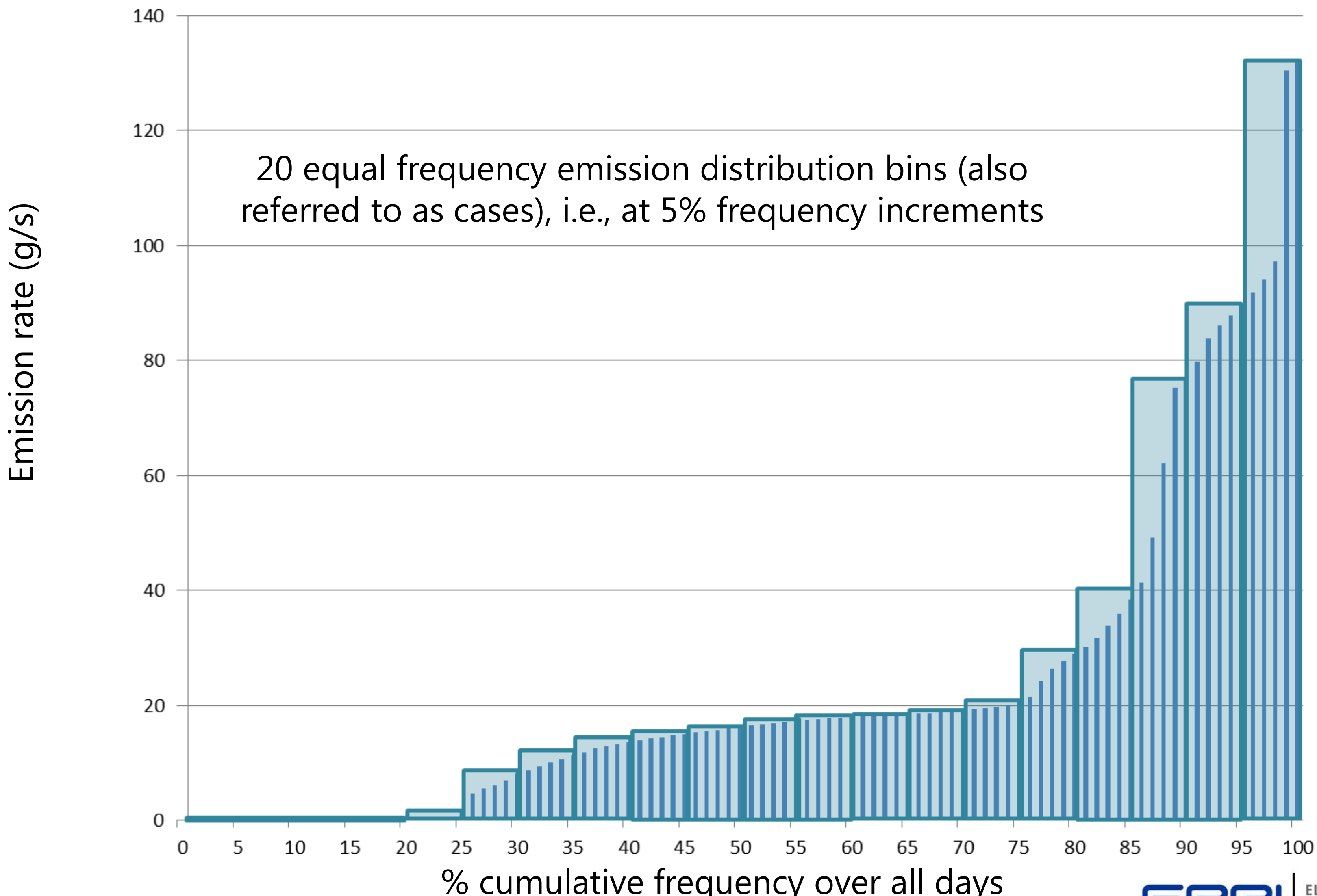

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Pre-processor Step to EMVAP: Run AERMOD for Each Defined Emission Case

- Model a constant 1 g/sec emission rate (adjusted later in EMVAP to the real emission rate)

- Apply either 1 year of on-site or 5 years of off-site hourly meteorological data, per USEPA guidance

- Specify a set of stack parameters for each discrete case
    - A separate set (stack height, diameter, location, exit velocity and temperature) for the top case if it represents bypass stack
    - Exit velocity and temperature could vary among cases if emissions variability is related to load
    - A single set of stack parameters could be used for all cases if emissions variability is related to fuel content or control device efficiency

- Run the model (AERMOD) for each set of stack parameters

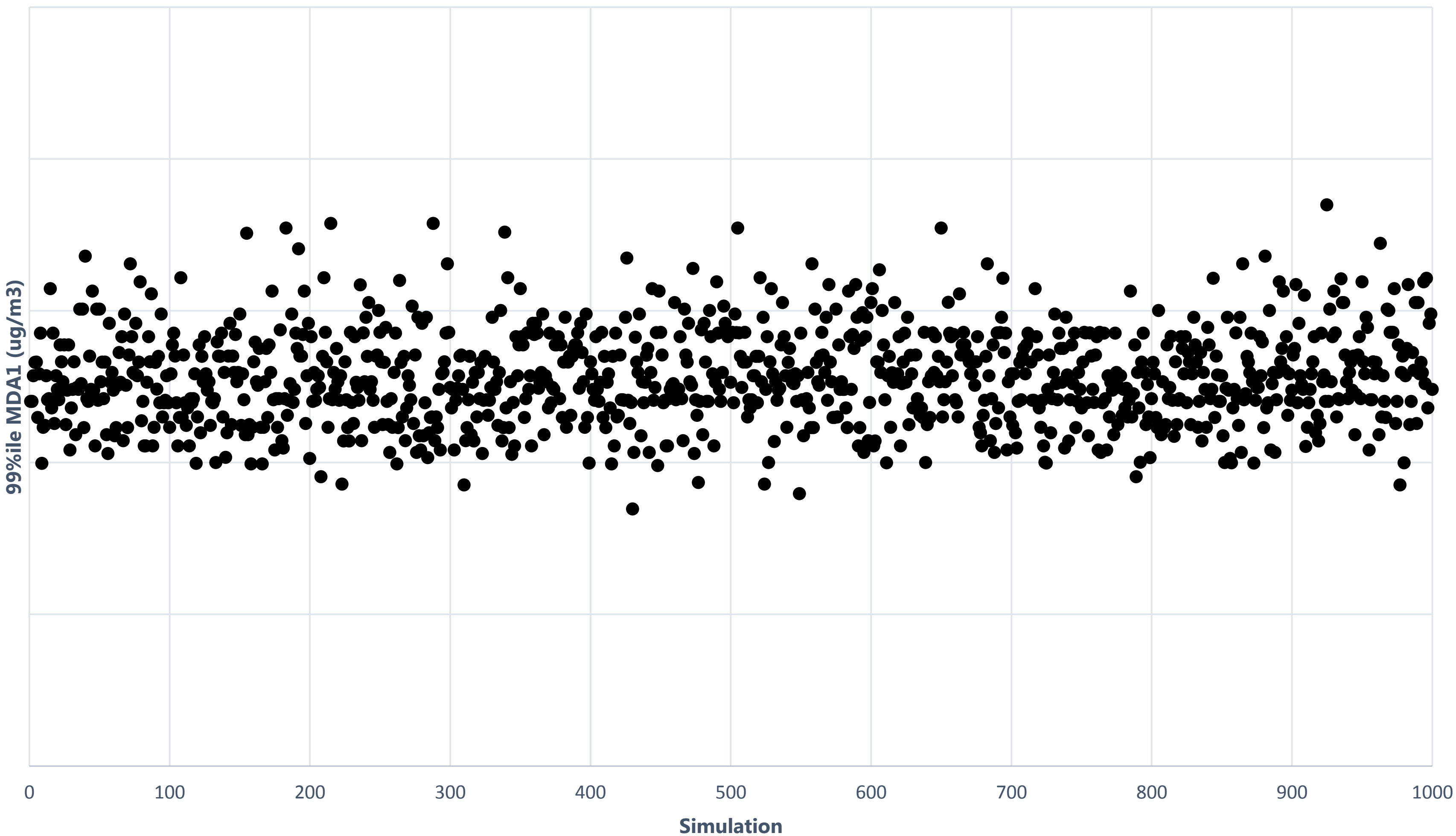
Apply EMVAP to Determine Design Concentration

- Specify number of simulations
  - At least 500 is recommended; several thousand can be run

- EMVAP randomly assigns an emission rate for each hour according to the discrete emissions distribution

- EMVAP processes appropriate summary statistics for each receptor for each yearly simulation
  - e.g., for SO_2 this is the daily maximum 1-hour concentrations (MDA1s)

EMVAP Design Concentration Results over 1000 Simulated Years



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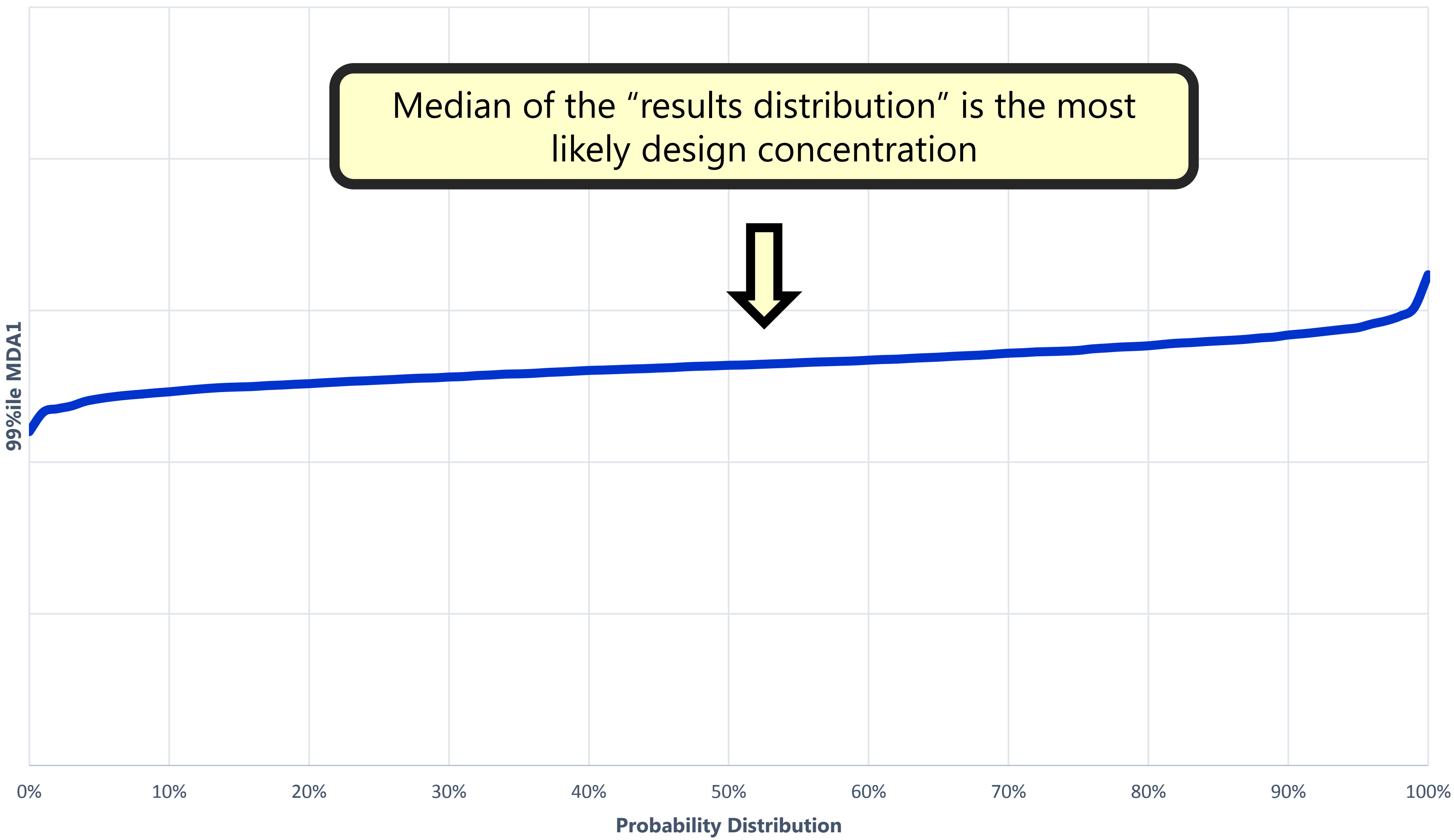

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EMVAP Evaluation Against Field Data

- Selected three AERMOD SO_2 databases
    - Databases had variable hourly emissions, stack parameters and ambient concentration measurements
    - Representing power plants in a variety of terrain settings
- Determined Emission Distributions and Emission Cases
- Ran AERMOD
    - For use in EMVAP
    - Also, with both actual and constant peak hourly SO_2 emissions
    - Computed 99th percentile peak daily 1-hour maximum at monitoring site receptors
- Ran EMVAP with 1000 simulations to estimate the “most likely” design concentration estimate
- EMVAP estimates were consistently between AERMOD results using actual emissions and constant peak emissions

EMVAP Testing with SO_2 Evaluation Databases

- **Lovett Generating Station:**
  - 1988, complex terrain within Hudson River Valley in New York
  - 1 full year test case, 8 monitors
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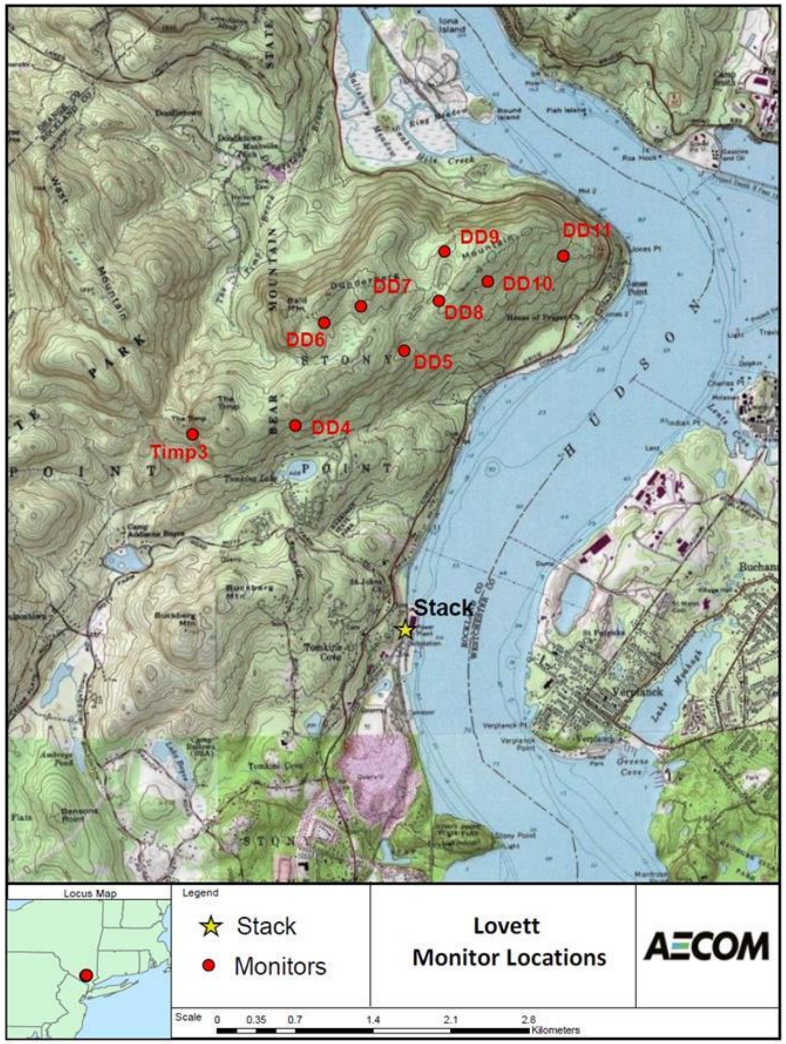
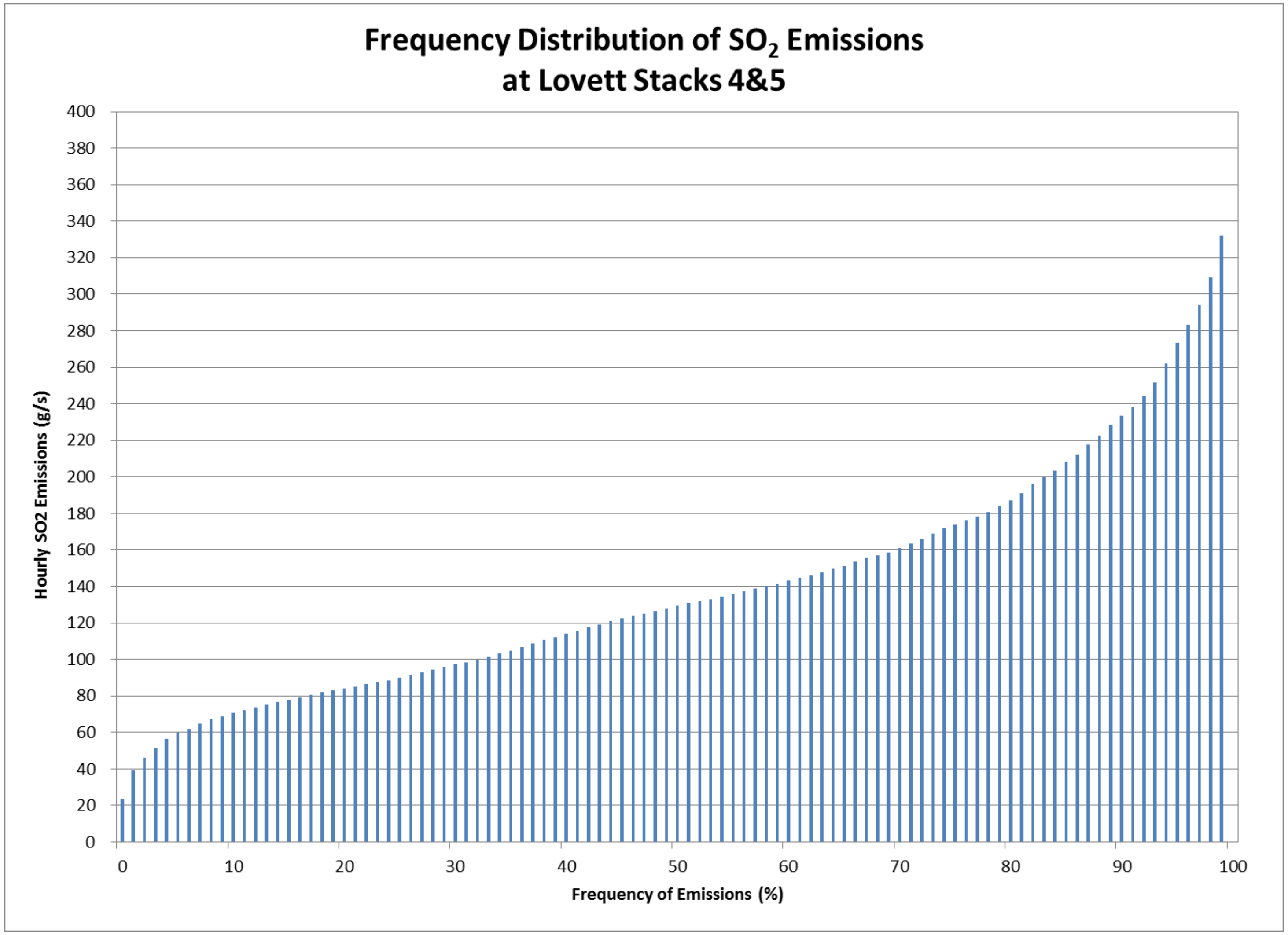
  - 1980, flat corn fields of Illinois
  - Partial year case, 1 stack, 28 monitors

Lovett Generating Station Database (1988)



Lovett Evaluation: Emissions Distribution (1)



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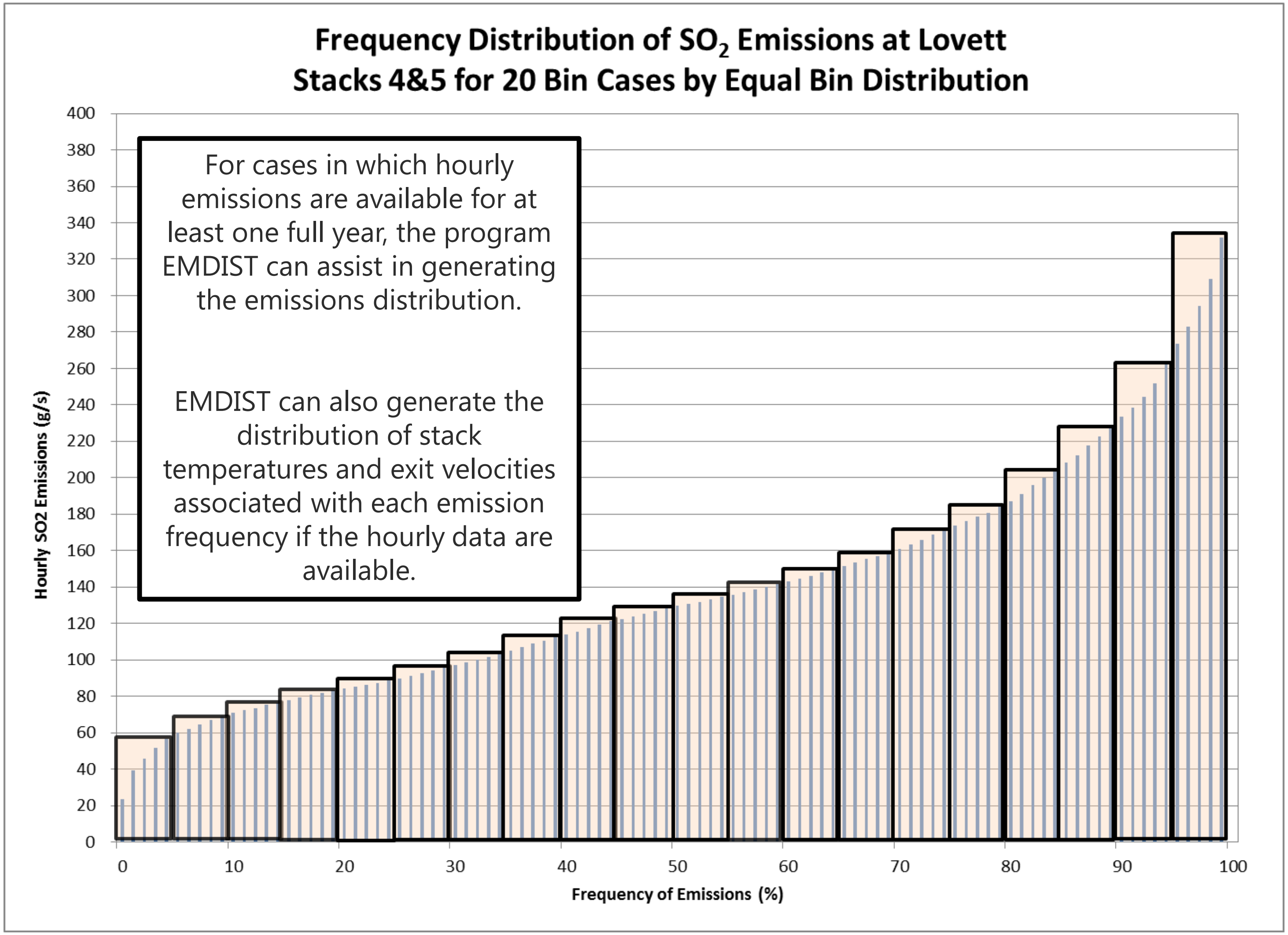
Lovett Evaluation: Emissions Distribution (2)



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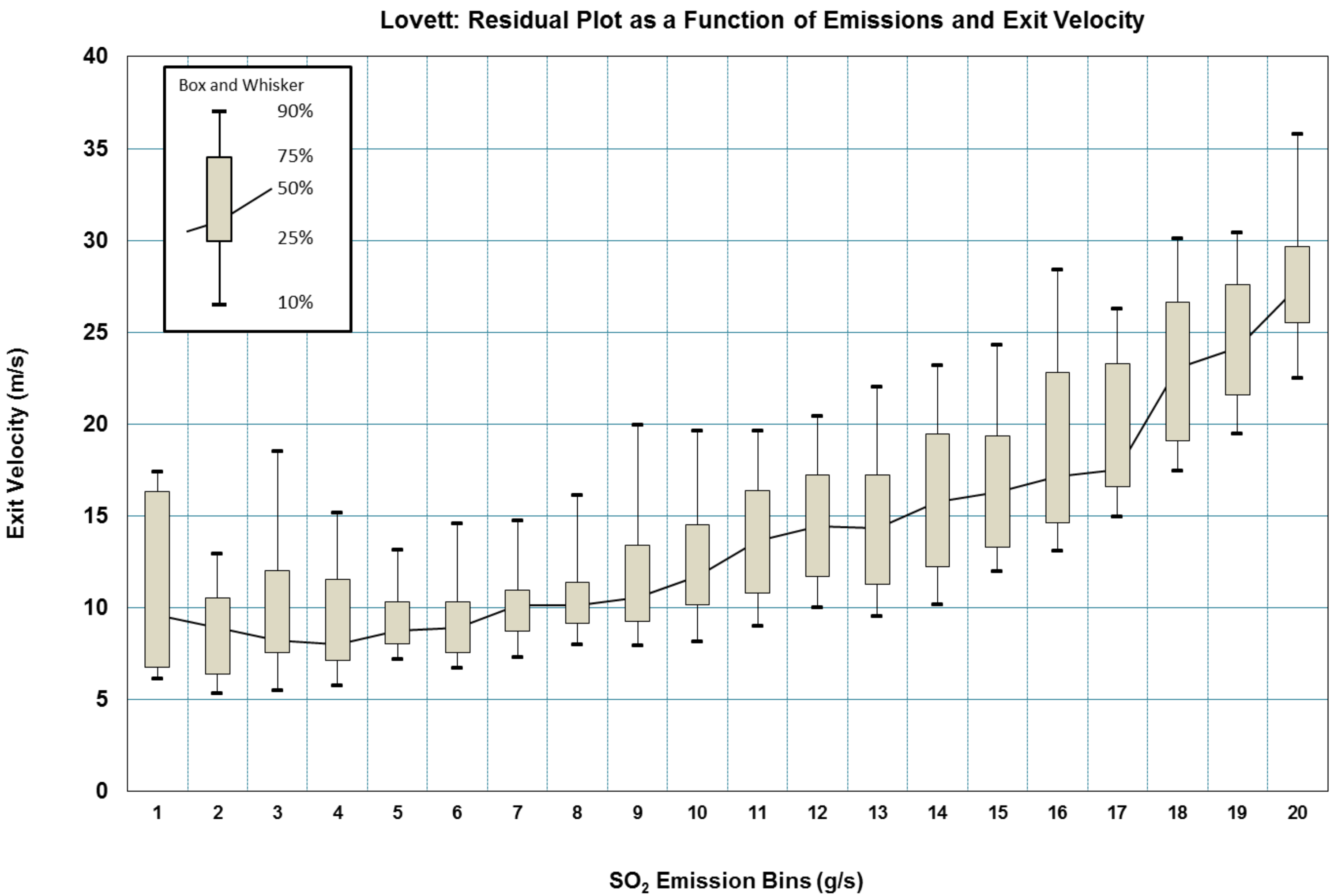
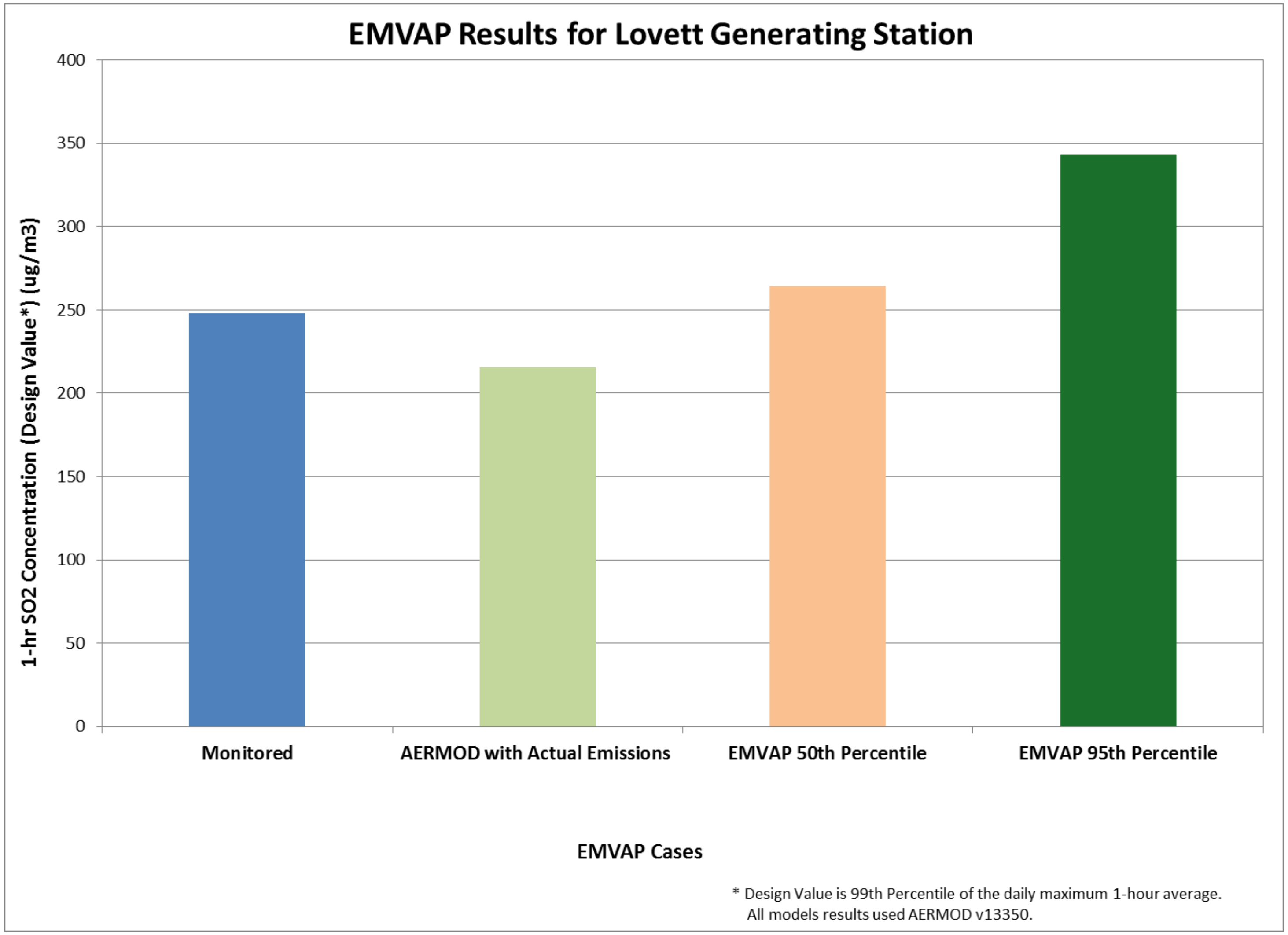
Lovett Example: Exit Velocity vs. Emission Rate



Lovett Example: Modeling Results



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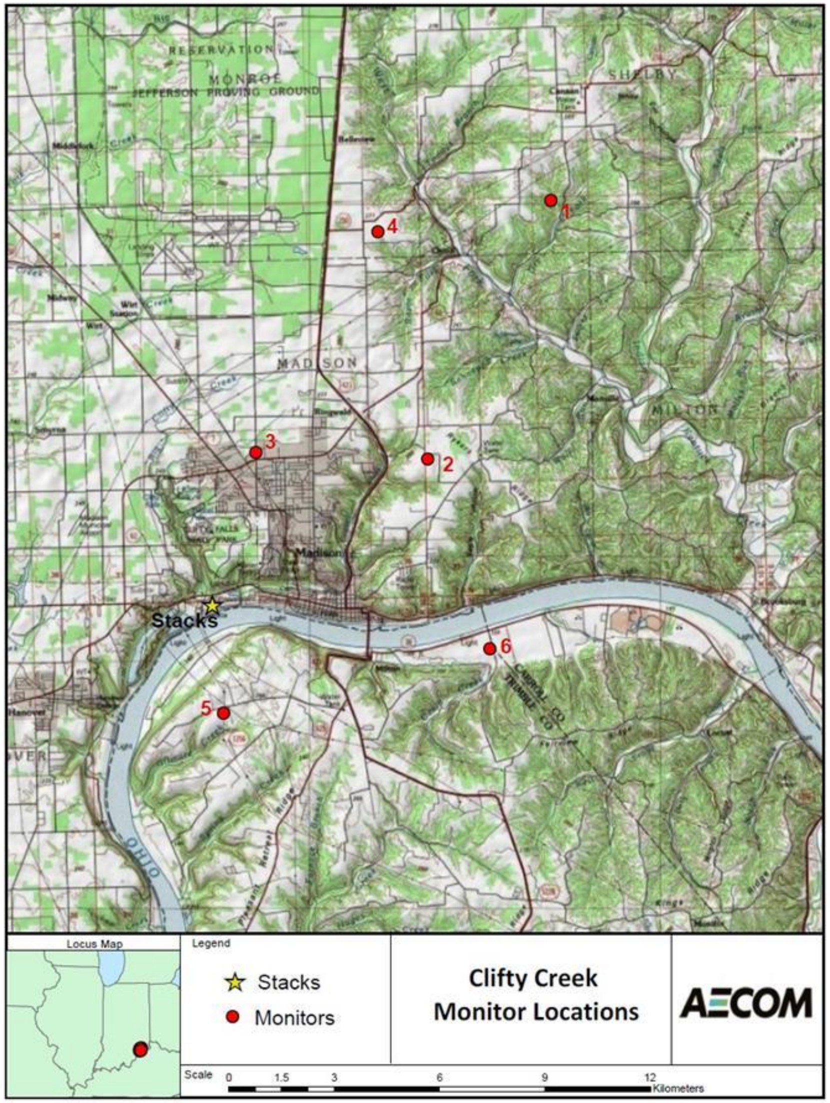
Clifty Creek Database (1975)



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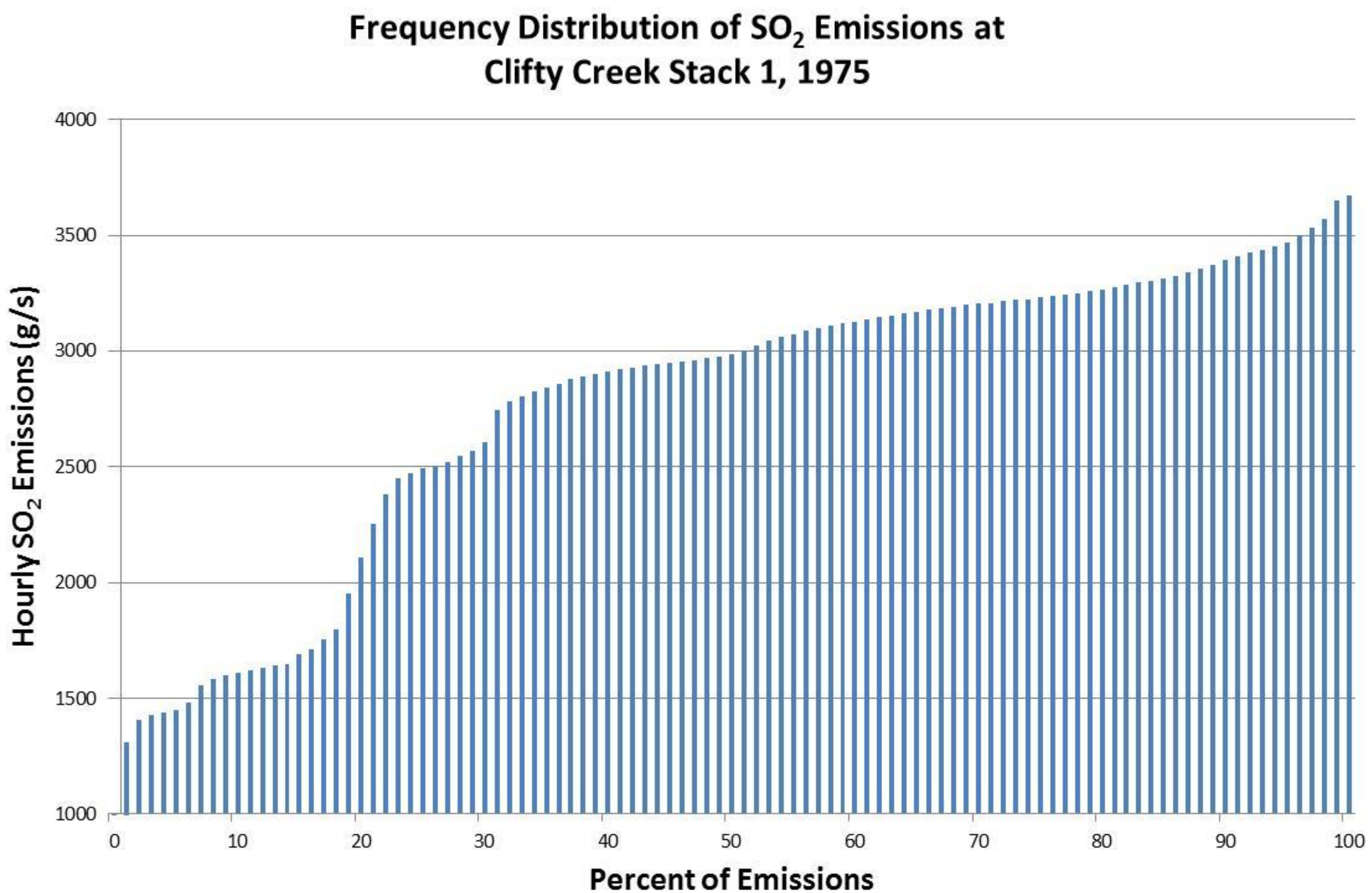
Clifty Creek Unit 1 Emissions Distribution



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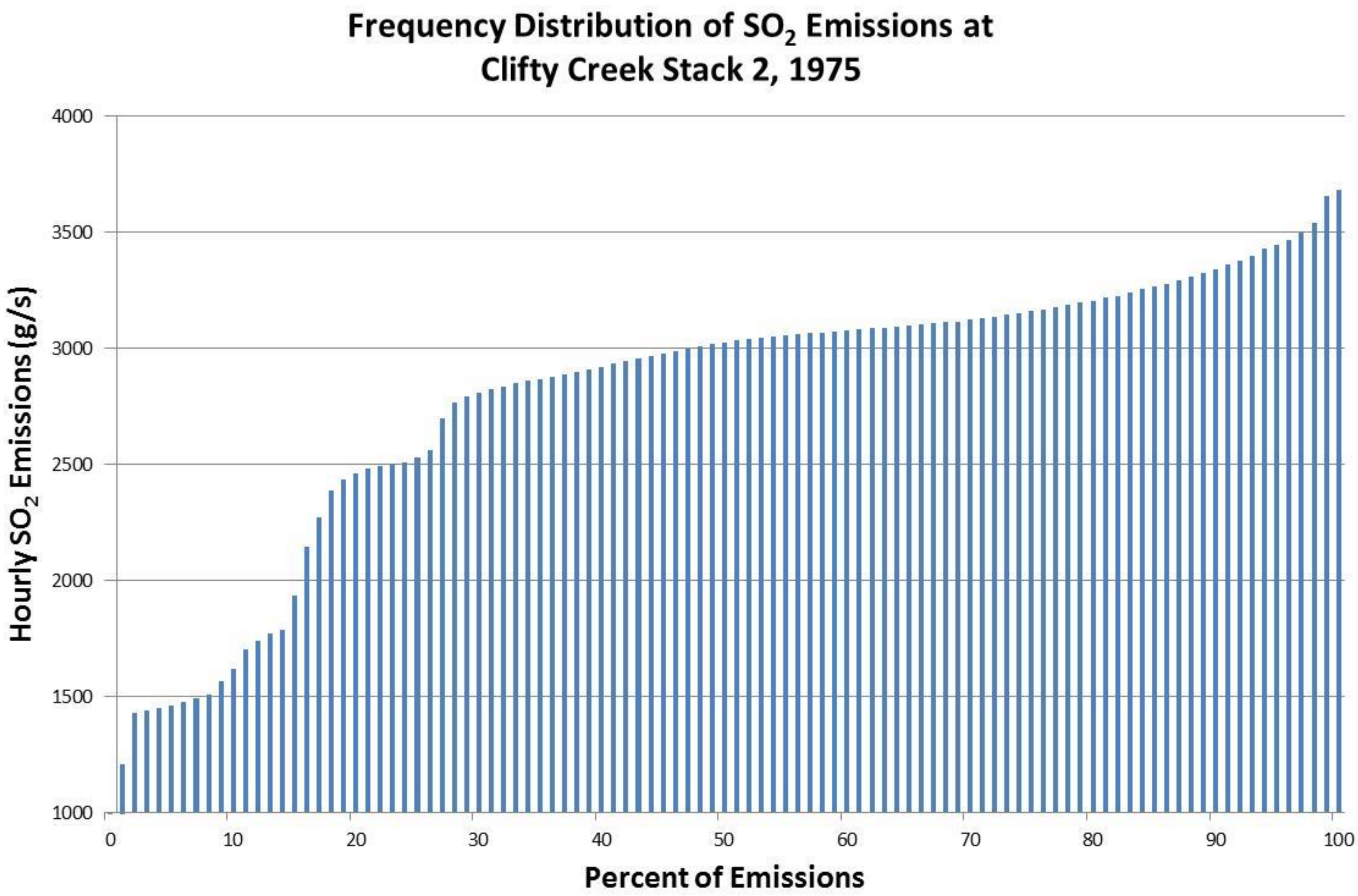
Clifty Creek Unit 2 Emissions Distribution



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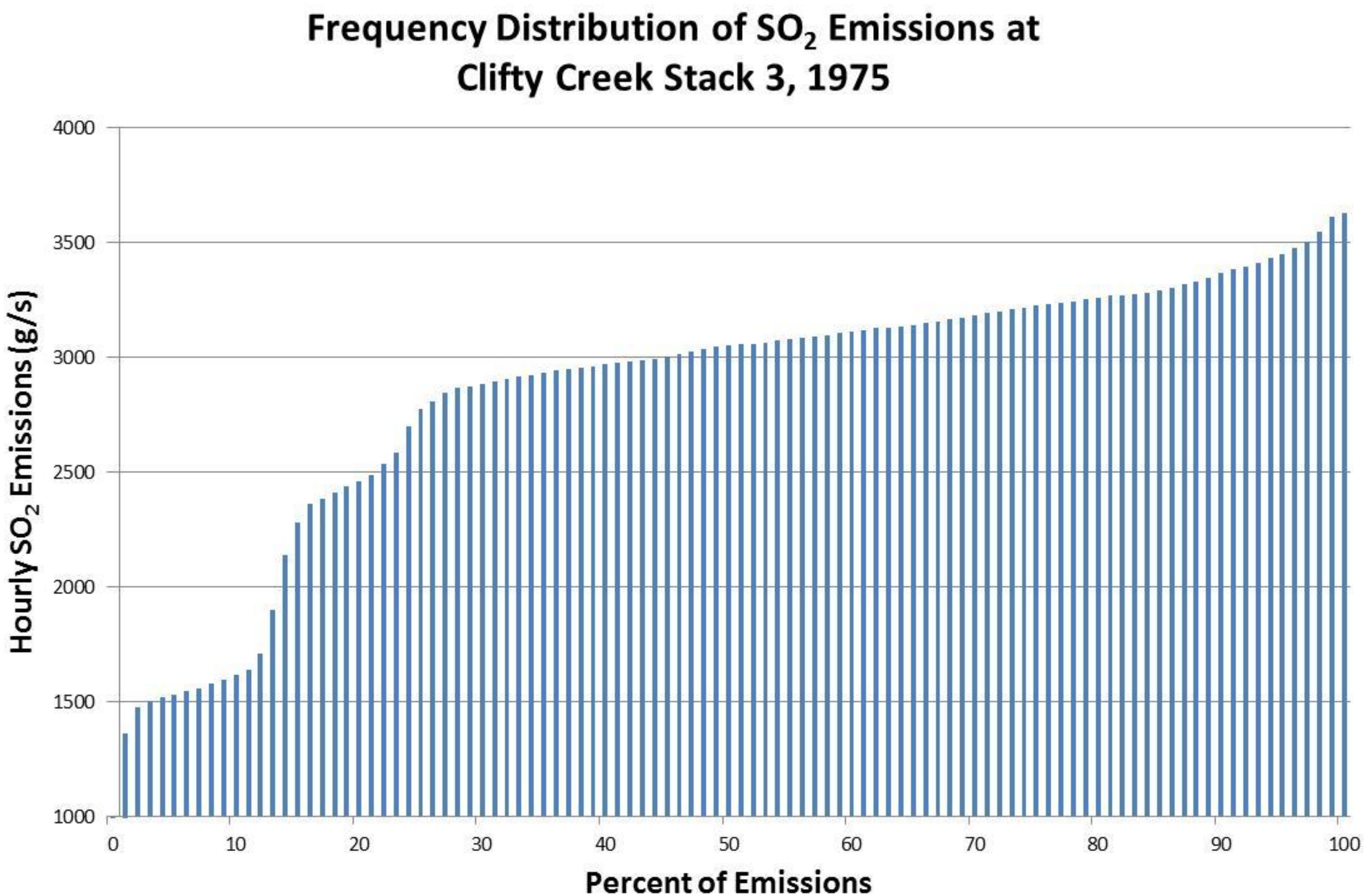
Clifty Creek Unit 3 Emissions Distribution



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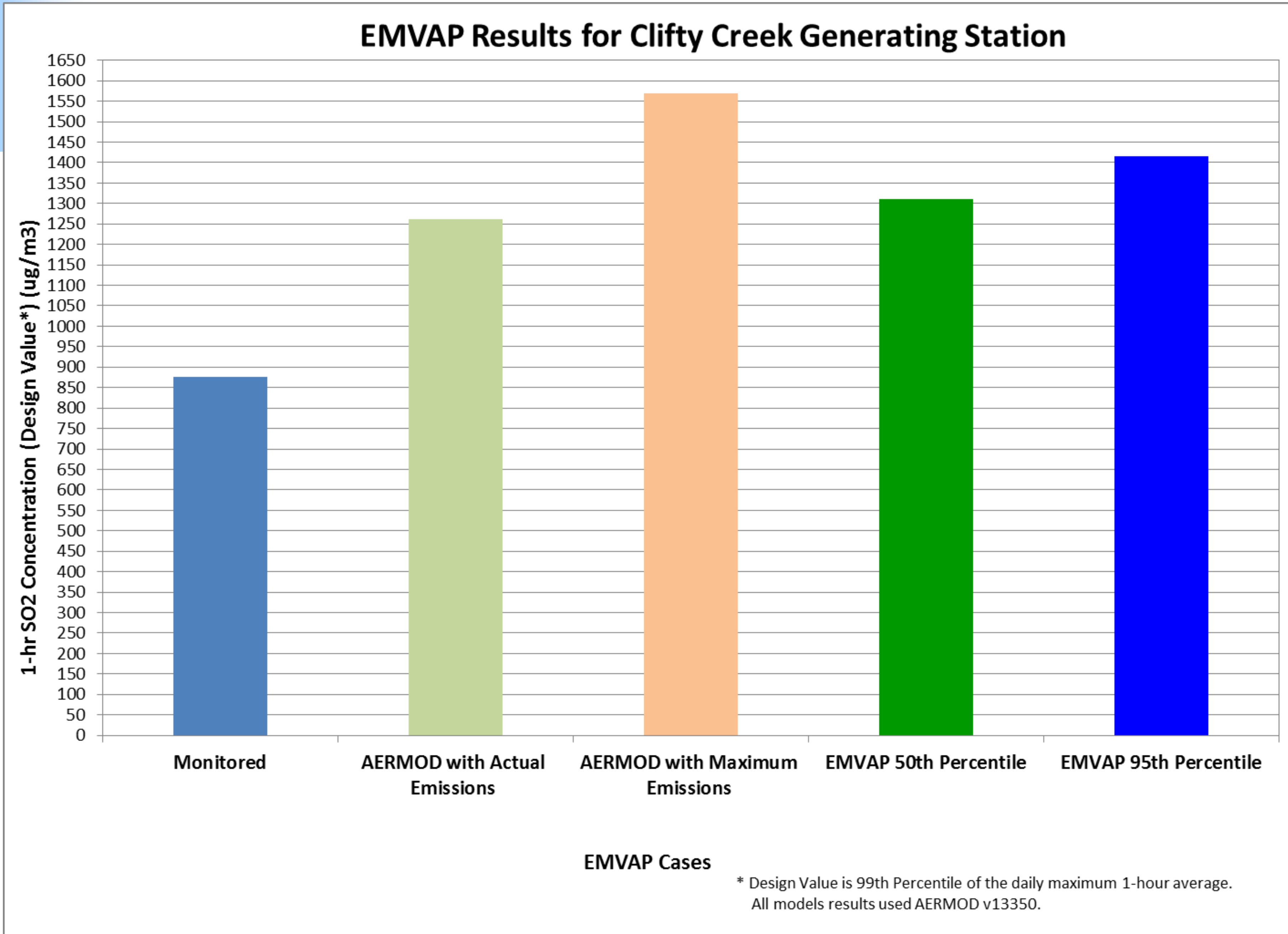
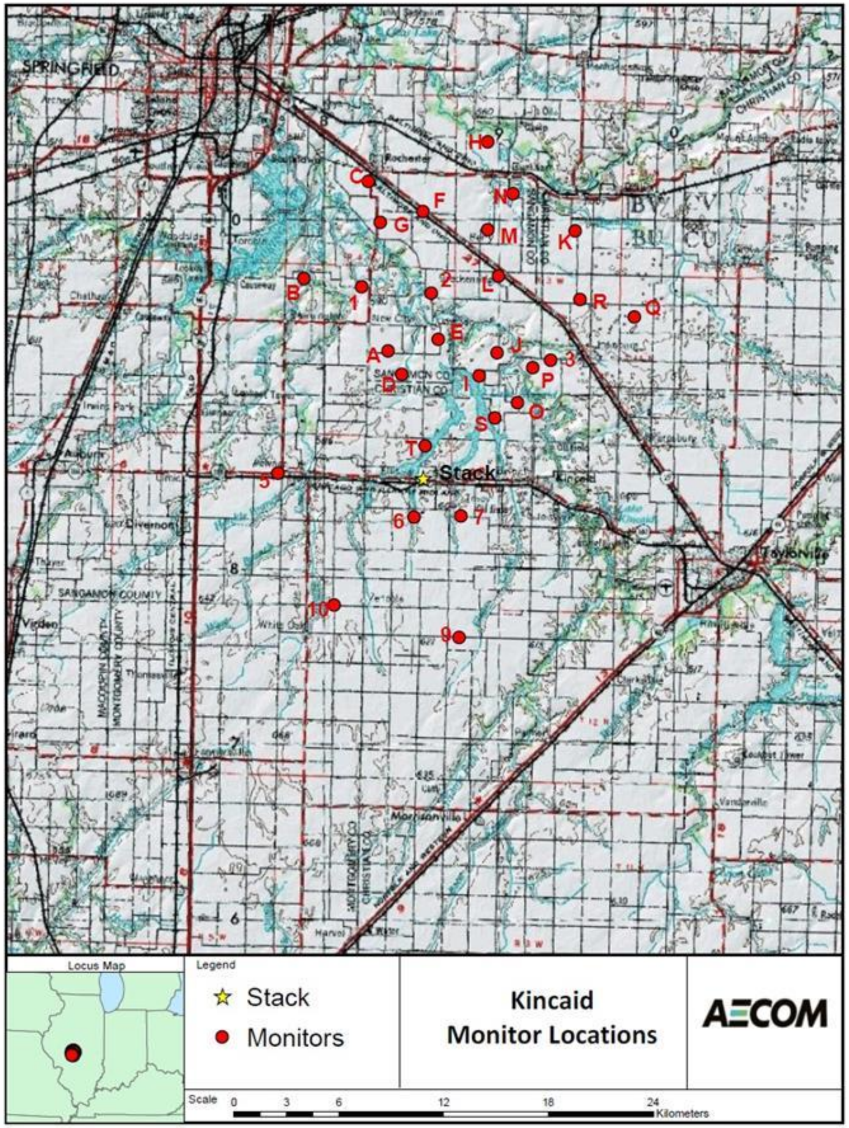

EMVAP Results for Clifty Creek Generating Station
1-hr SO2 Concentration (Design Value*) (ug/m3)
1650
1600
1550
1500
1450
1400
1350
1300
1250
1200
1150
1100
1050
1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Monitored
AERMOD with Actual Emissions
AERMOD with Maximum Emissions
EMVAP 50th Percentile
EMVAP 95th Percentile
EMVAP Cases
* Design Value is 99th Percentile of the daily maximum 1-hour average.
All models results used AERMOD v13350.

Kincaid Generating Station Database (1980-81)



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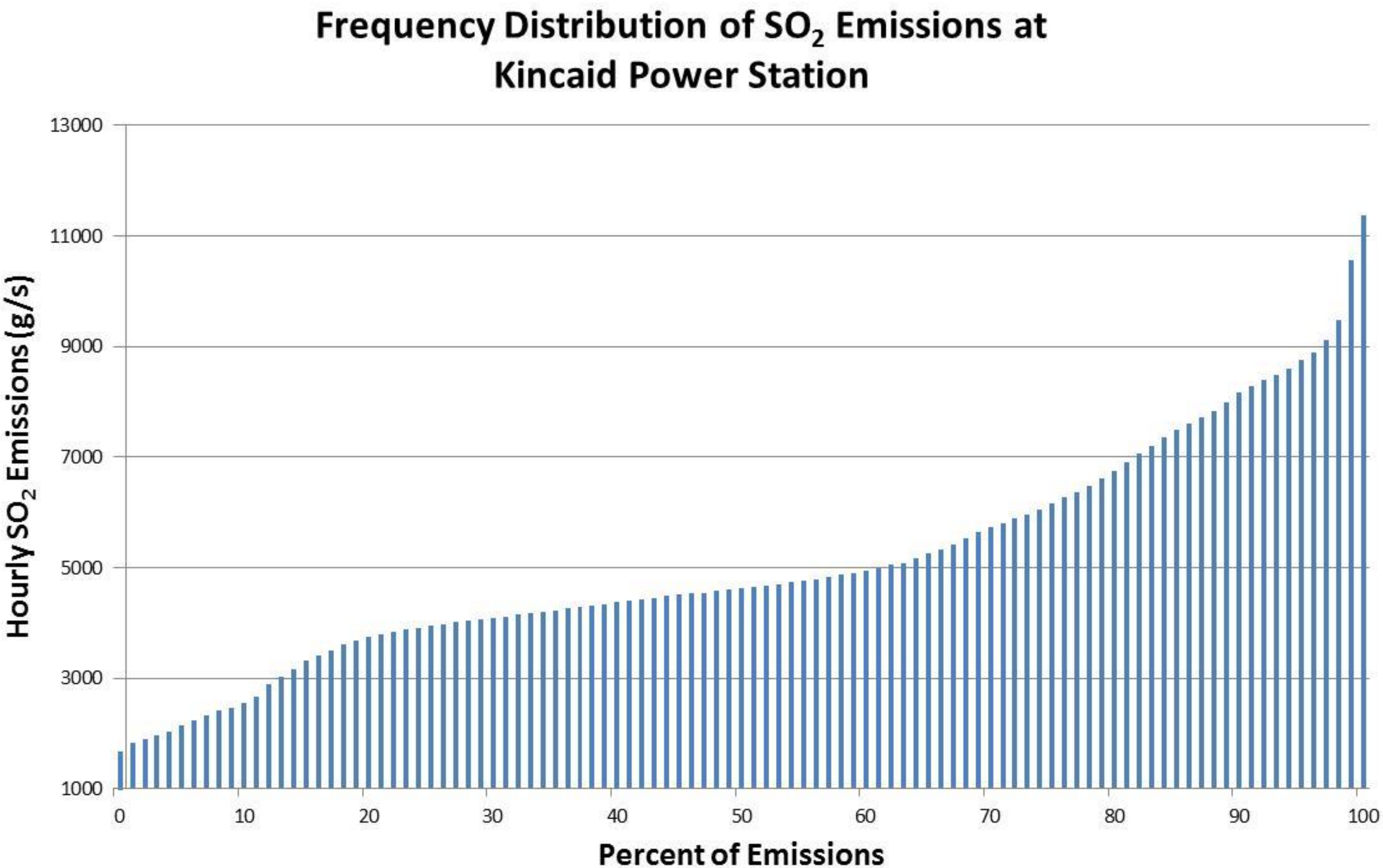
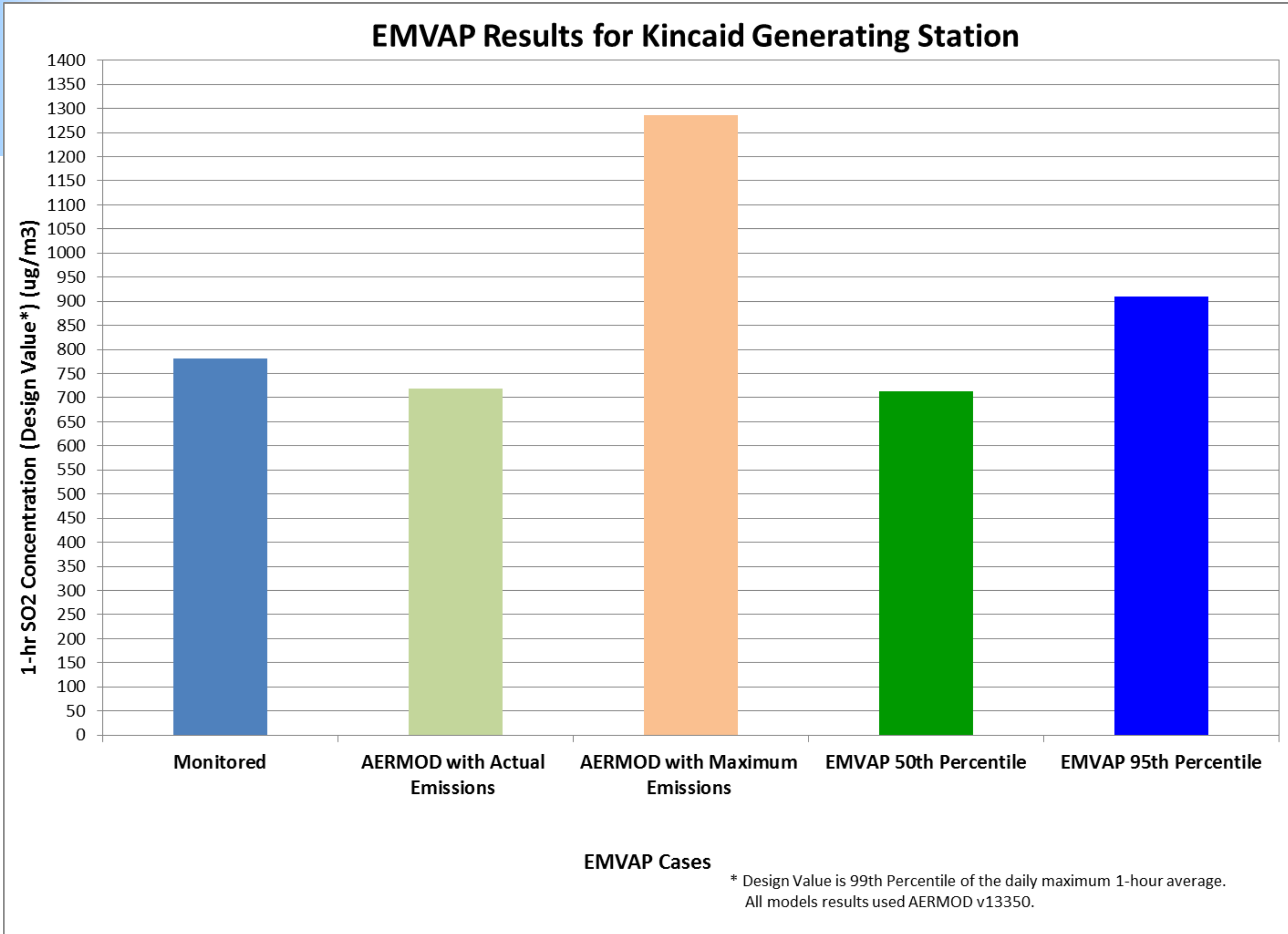

Frequency Distribution of SO_2 Emissions at Kincaid Power Station
Hourly SO_2 Emissions (g/s)
13000
11000
9000
7000
5000
3000
1000
0
10
20
30
40
50
60
70
80
90
100
Percent of Emissions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1400
1350
1300
1250
1200
1150
1100
1050
1000
950
900
850
800
750
700
650
600
550
500
450
400
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300
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Overall Evaluation Results for EMVAP (1)

- Evaluation results suggest that EMVAP can provide a realistic design concentration estimates, even when a source has infrequent high emissions or a wide variety of emissions

- EMVAP's assumption that hourly emissions are random and independent rather than clustered adds conservatism to the design concentrations
  - Peak emissions are spread over more days than they actually occur
  - Standard only chooses one value from each day, thus the "unclustering" of emissions can spread high emissions over more meteorological regimes

Overall Evaluation Results for EMVAP (2)

- Use of EMVAP results in design concentrations (using median of the design concentration distribution) that are at least as high as modeling with actual hourly emission rates

- This is true for the 50th percentile results, and EMVAP is even more protective for higher percentile results

- Now that this demonstration is made, we can evaluate how EMVAP can be used to evaluate how emissions variability can affect the appropriate longer-term complying emission rate to protect a 1-hour NAAQS

- The technical nature of this method is described in the following slides

Is EMVAP Protective of Air Quality for Your Case?

- Some commenters have wondered about certain cases in which there are unique emission distributions such as seasonal emission differences
- Is EMVAP protective of air quality in those situations?
- Fortunately, this can be easily tested, as follows:

1) Construct an hourly emissions file (at least 1 year in duration) for the case to be tested

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- Previous EPA guidance:
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- EPA would expect that any emission limit with an averaging time longer than 1 hour would need to reflect a downward adjustment to compensate for the loss of stringency inherent in applying a longer term average limit.

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- The downward adjustment depends upon the intermittency and variability of the longer-term emissions (more variability → more downward adjustment)

- **The Emissions Variability Processor (EMVAP) developed by EPRI can be used as a tool to address emissions averaging**

Steps for Using EMVAP to Calculate a Long-Term Average Emissions Rate

- Step 1: Determine the 1-hour average "critical value" using AERMOD
- Step 2: Choose an emission distribution that is applicable to future operation
- Step 3: Set up EMVAP with the emission distribution
- Step 4a: Run EMVAP with a starting long-term emission rate equal to the critical value to determine a downward scaling factor needed to show NAAQS compliance that accounts for the emissions distributions
- Step 4b: Rerun EMVAP with scaled emissions to verify NAAQS compliance – this may require more than one iteration

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Find Critical Value (AERMOD) with constant 1-hour emission rate

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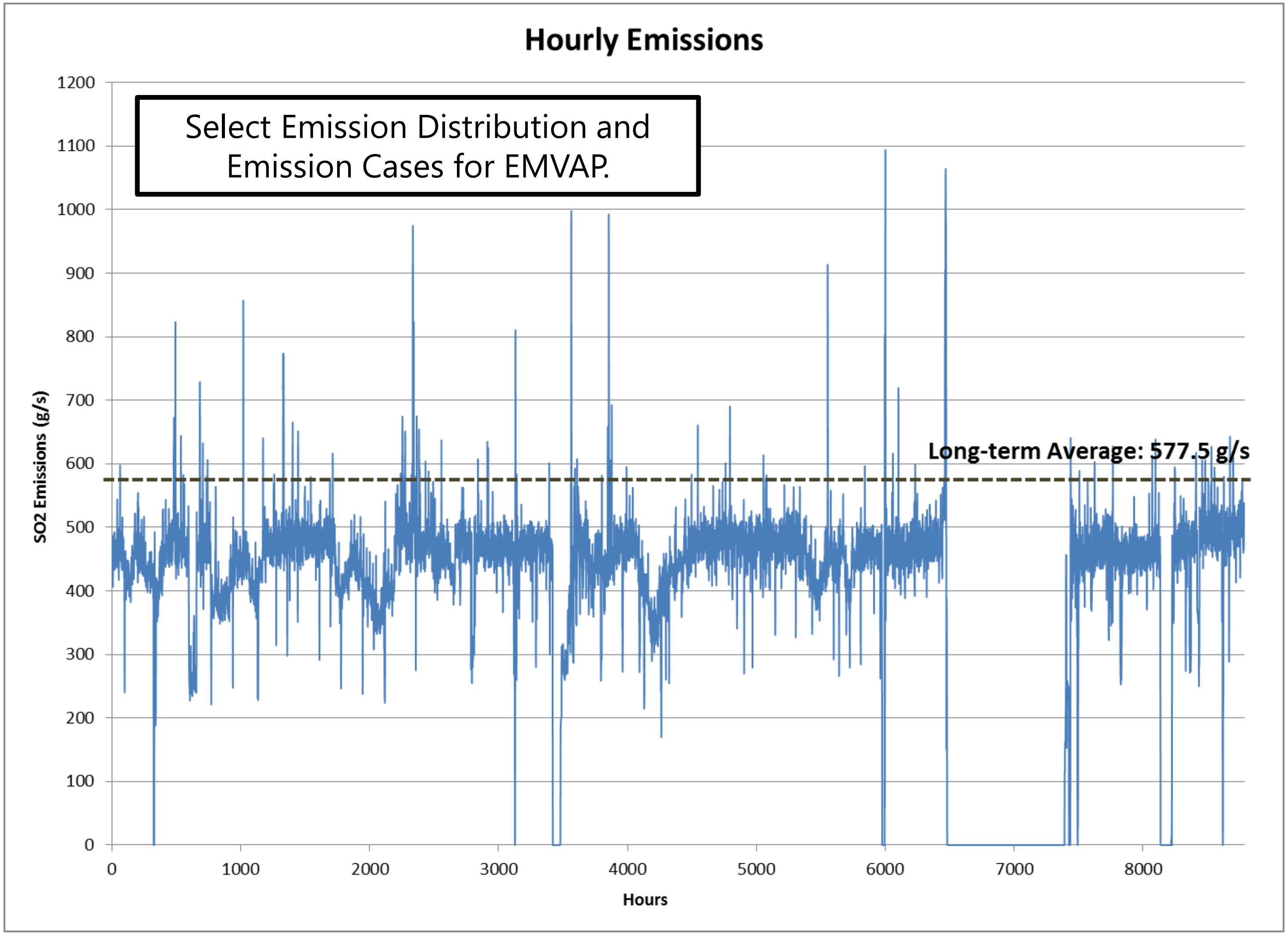

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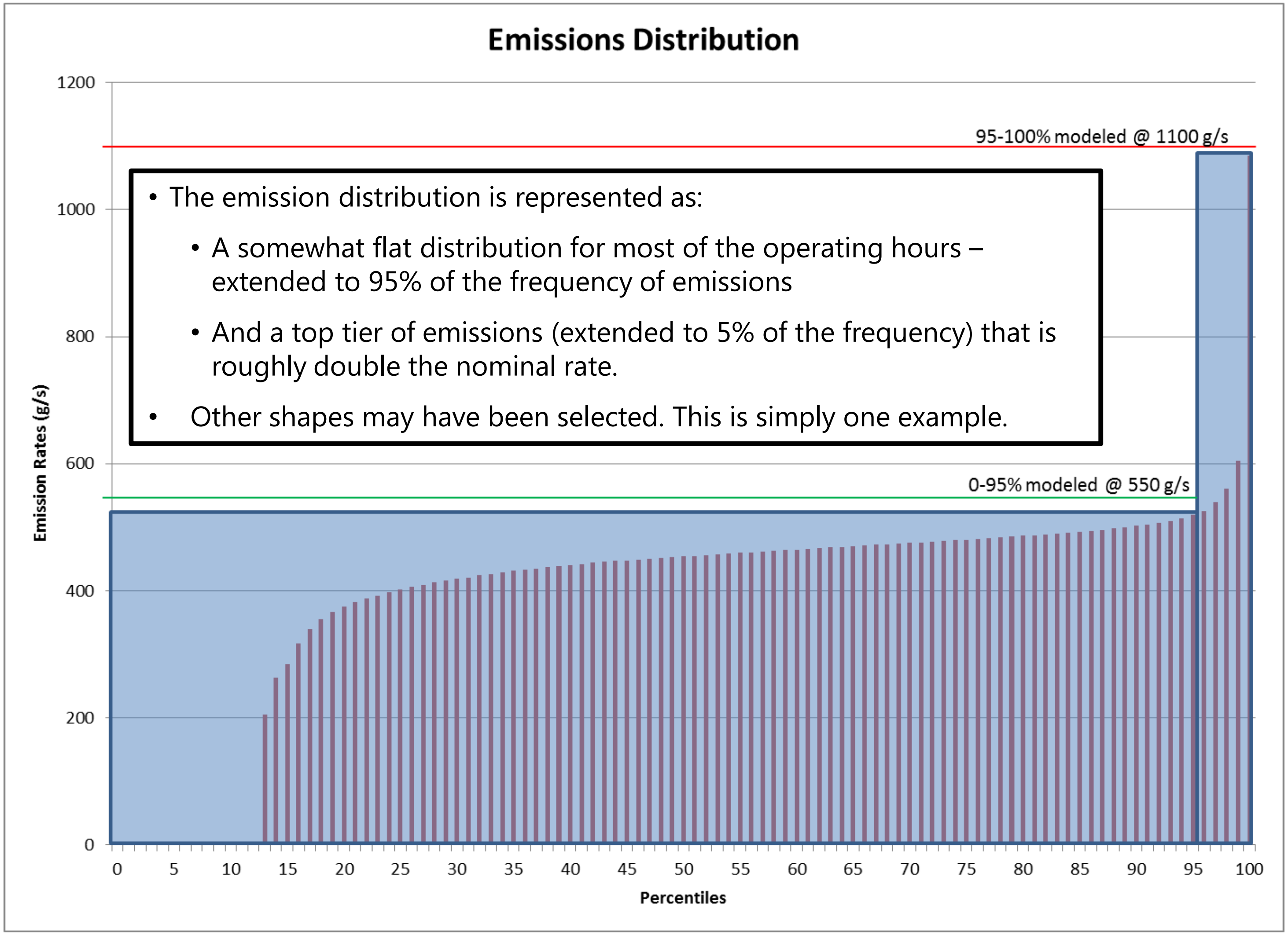
Step 2 (Continued): Emissions Distribution



- The emission distribution is represented as:
  - A somewhat flat distribution for most of the operating hours – extended to 95% of the frequency of emissions
  - And a top tier of emissions (extended to 5% of the frequency) that is roughly double the nominal rate.
- Other shapes may have been selected. This is simply one example.

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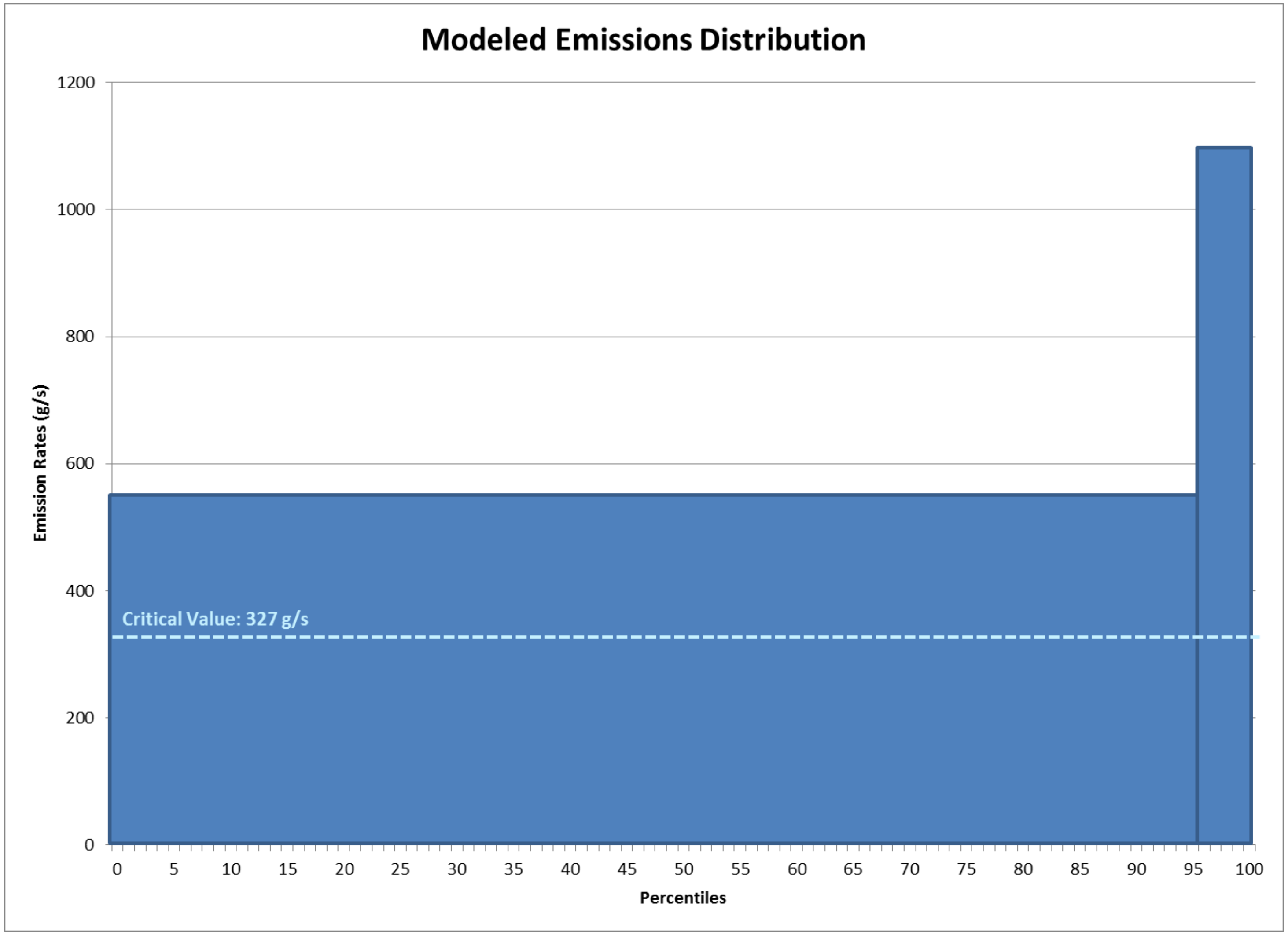

Example Application of EMVAP: Step 3

Generate AERMOD Binary Files for each Emission Distribution case.

AERMOD

If the stack parameters vary between the emission distribution bins, a separate source must be modeled for each emission bin*.

Each source must be run with:

- 1 g/s emission rate
- corresponding stack parameters for that bin in the emissions distribution

These binary files will be used in the EMVAP run.

*Refer to EMVAP User's Guide for details.

Example Application of EMVAP: Step 4a

Estimate the Compliant Emission Rate using EMVAP – Part 1.

Inputs:

- Ambient Background Value
- Critical Value for 1-hour Emission Rate (Step 1)
- Emissions Distribution (Step 2)
- AERMOD Binary Files (Step 3)

EMVAP: Initial run - two options:
a) Select the Critical Value Analysis Option; this option normalizes the Emission Distribution and scales it based on the Critical Value

b) Run EMVAP normally with a first emissions guess to see how high the predicted design conc. is.

Output for the two options:

a) Scaling Compliance Ratios (CR) for a distribution of EMVAP Design Concentrations are listed at the end of the NAAQS table. This can be used for the Step 4b (additional EMVAP runs)

b) Normal EMVAP results can be used to manually estimate a scaling of emissions to obtain NAAQS compliance for a result from the next EMVAP run(s).

***This method is illustrated for a single emission source**.

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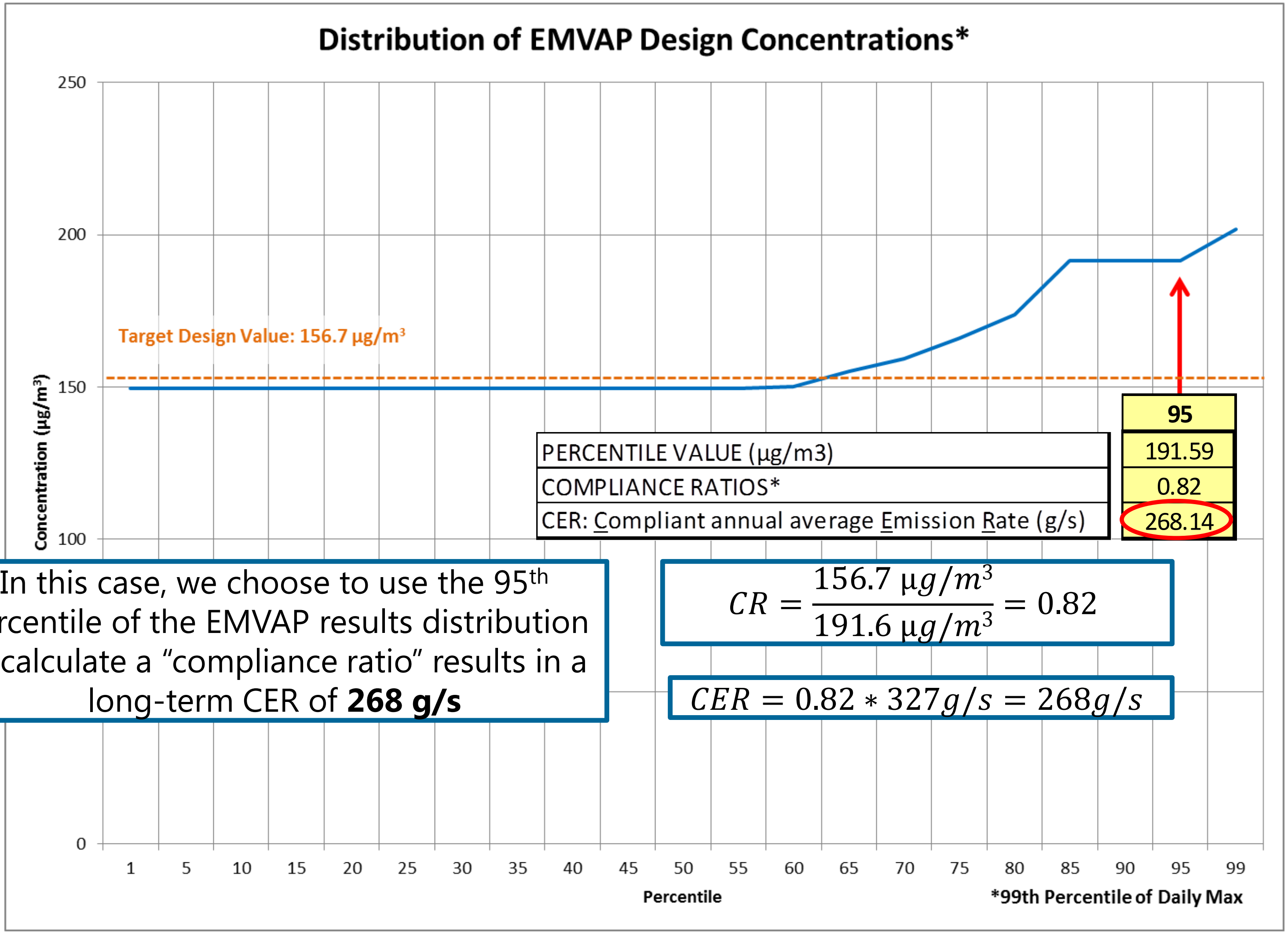
Example Application of EMVAP: Step 4a

*Based on a Target Design Value of 156.7 µg/m3 (which takes into account an ambient background of 39.3 µg/m3)



	95
PERCENTILE VALUE (µg/m3)	191.59
COMPLIANCE RATIOS*	0.82
CER: Compliant annual average Emission Rate (g/s)	268.14

In this case, we choose to use the 95th percentile of the EMVAP results distribution to calculate a "compliance ratio" results in a long-term CER of **268 g/s**

$$CR = \frac{156.7\ \mu g/m^3}{191.6\ \mu g/m^3} = 0.82$$

$$CER = 0.82 * 327 g/s = 268 g/s$$

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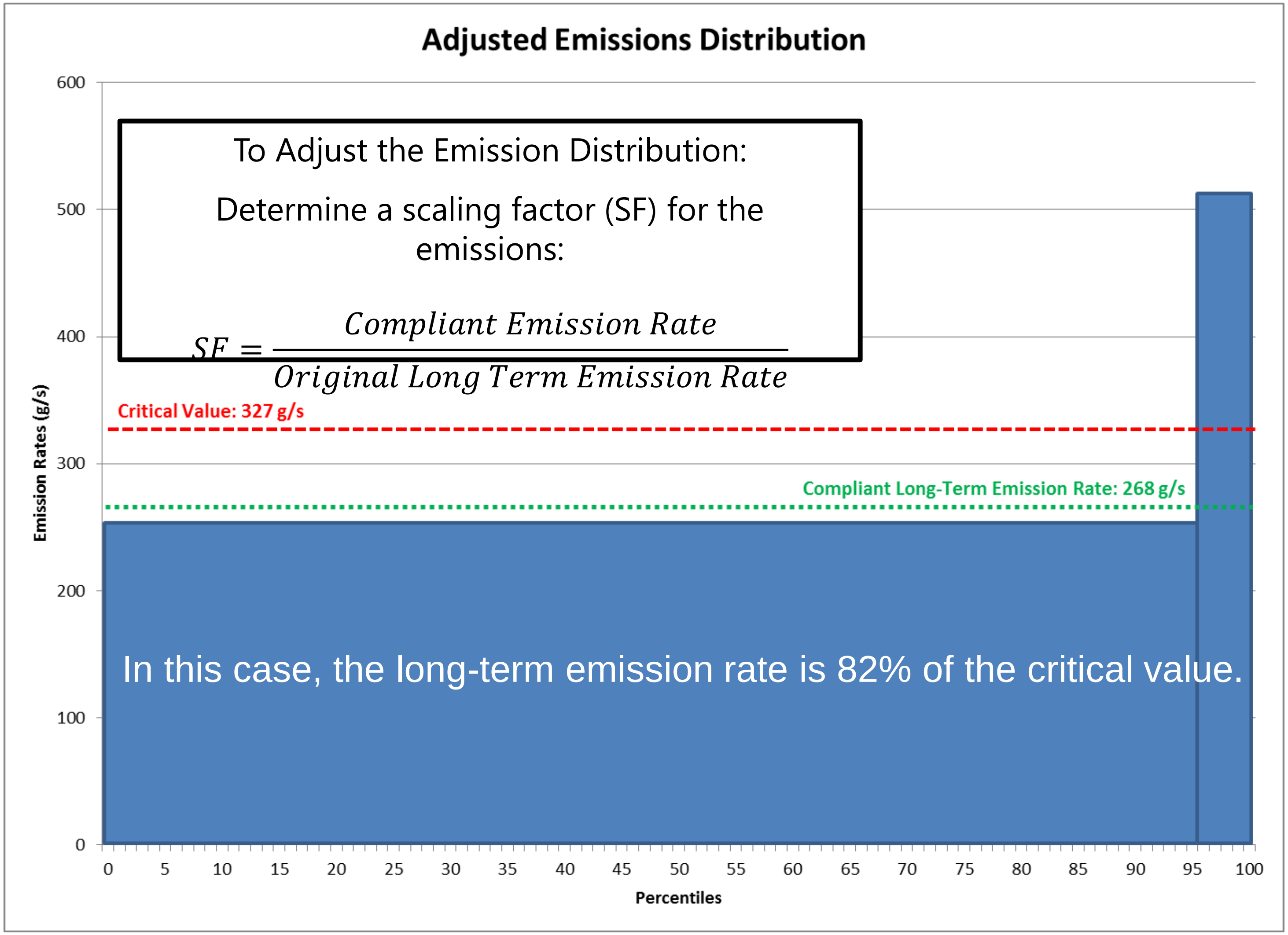
Example Application of EMVAP: Step 4b

Rerun EMVAP with scaled emission rates to verify modeled NAAQS compliance.



To Adjust the Emission Distribution:

Determine a scaling factor (SF) for the emissions:

$$SF = \frac{Compliant\ Emission\ Rate}{Original\ Long\ Term\ Emission\ Rate}$$

In this case, the long-term emission rate is 82% of the critical value.

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Example Application of EMVAP: Step 4b

Verify NAAQS compliance with the scaled emission rate using EMVAP:

Inputs:

- Scaled Emissions Distribution (Step 2 and Step 4, Part 1)
- AERMOD Binary Files (Step 3)

↓

Run EMVAP

Do not Select the CV Analysis Option;

Run EMVAP in the Normal Mode

↓

Output:

Design Value Result to be Compared to the NAAQS

Iterate Step 2 as needed – this is a useful step for multiple sources run with EMVAP

Current Status of EMVAP

EMVAP version 14044 has implemented the following changes:

- Implementation of ARM2 procedure for the 1-hour NO_2 NAAQS
- Acceptance of an ambient background value to calculate the NAAQS Target Design Value.
- Calculation of a distribution of Long-term Compliance Ratios and Emission Rates.
- Implementation of the Critical Value Analysis option.

Overall Conclusions

- EMVAP is a useful tool for applications involving new or modified sources
- The EMVAP approach is consistent with the probabilistic form of the 1-hour SO_2 and NO_2 NAAQS
- Evaluations of EMVAP consistently show modest levels of conservatism, even using the median of the “results distribution”
- EMVAP can be used to evaluate long-term average emission limits that are protective of a 1-hour NAAQS standard – we show an example of how this can be done

- Public domain tool:
  - http://sourceforge.net/projects/epri-dispersion/
  - Old version currently on site… new version will be posted within first half of 2014